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NATURAL VENTILATION FOR FALLOUT SHELTERS

THE PENNSYLVANIA STATE UNIVERSITY
UNIVERSITY PARK, PENNSYLVANIA

INTERIM REPORT

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INTERIM REPORT

NATURAL VENTILATION FOR FALLOUT SHELTERS

a research project conducted by

The Department of Architectural Engineering
and
Institute for Building Research
The Pennsylvania State University
University Park, Pennsylvania

prepared for

Office of Civil Defense
Department of the Army -- OSA
under
Subcontract No. B-64201-US
Subtask 1231B

OCD DISTRIBUTION NOTICE

This interim report describes environmental tests performed in a specific shelter. The discussion of the results is preliminary and should not be used as the basis for general conclusions. A subsequent final report will include a comparative evaluation of data from subsequent tests having a variety of configurations and locations.

31 January 1966

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PREFACE

Natural ventilation of a building is frequently preferred to mechanical ventilation for several reasons, among which are reduced cost, absence of noise producing equipment, and ease of maintenance. However, modern buildings are usually equipped for mechanical distribution of conditioned air for reasons which are obvious and outside the scope of this study. During an emergency, the ventilation of a shelter space inside a building poses problems which are different from those encountered in normal, day-to-day occupancy, and these problems may best be solved with the use of natural ventilation alone. Such a situation would exist in the event of electrical power failure.

When a space is occupied by people, heat is produced which, in turn, will stimulate a certain amount of natural circulation if circulation paths are available. Vertical stacks in buildings, such as stair towers and elevator shafts, together with appropriately situated open doors will constitute a proper air circulation path. Air infiltrating from the exterior can insure satisfactory quality of inside air and, under certain conditions, prevent effective temperatures from rising too high in occupied spaces.

In this study the natural ventilation of eight-story dormitory type buildings without benefit of electrical power is investigated.

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ABSTRACT

Two identical eight-story dormitory buildings on the campus of The Pennsylvania State University were used for investigating natural ventilation effects. Equipment for measuring air change rates, consisting of an electronegative gas detector, a system of plastic pipe, a collection and valve control device, and necessary recording instruments, was used to gather data. Results are reported on ventilation of a closed, unoccupied building, and on ventilation of shelters in the basement and on the fifth floor with simulated occupants. A portable ventilation fan and opening of selected exterior doors were used in several tests to determine the possibility of increasing ventilation rates. Generally, ventilation of shelter spaces was lower than expected and below that which would be needed in hot, humid weather when such spaces were occupied to the normal density limit. Neither changing exterior temperature nor moderate winds had significant affects on ventilation rates of the closed buildings under conditions encountered during the testing period.

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INTRODUCTION

SECTION 1.0 INTRODUCTION

1.1 NATURAL VENTILATION

This study involves the natural ventilation of buildings. Natural ventilation can be defined as the movement of air in and out of the building through cracks and openings such as windows, doors, and ventilators, with independence of any mechanical device. As used here, however, it is possible to enhance natural ventilation through expedient methods such as portable fans, opening doors and windows at strategic locations, or by providing heat sources on or near the base of natural draft stacks.

1.2 IMPORTANCE TO THE SHELTER PROGRAM

Many buildings today have mechanical ventilation dependent on electrical power. Emergencies may arise during which the fans and other equipment contributing toward ventilation are rendered inoperative. With power still available, filters would be required in those buildings where considerable mechanical ventilation is used to provide an adequate quantity of outdoor air. With mechanical equipment available and operative for the ventilation of buildings, changes such as rewiring, reswitching, and relocation of equipment might be necessary to provide ventilation for designated emergency shelter spaces within the building.

For the above reasons, it is desirable to have a building which is not completely dependent on the presence of mechanical devices for the emergency occupancy of people in designated shelter spaces. Unquestionably, if shelter spaces are usable without mechanical ventilation, many more such spaces will be available. An

investigation of the practicability of natural ventilation is, therefore, of real and immediate importance to the national shelter program.

1.3 BACKGROUND OF THE PROJECT

A research project concerning the measurement of natural draft was concluded and reported on in December, 1963 by the College of Engineering of The Pennsylvania State University.[1] One of the prime objectives of that project was to evaluate the amount of natural ventilation one can expect in a building with occupied shelter space in the basement or underground. It was recommended at that time that a follow-up study be made with occupied shelter space in an upper story of a multi-story building. This led to the award of a contract, the results of which are reported herein.

As stated in the earlier project report, there is available today a wealth of pertinent information concerning the effects of overcrowding[2] and the tolerance ranges of human beings for various conditions of the atmosphere.[3,4,5] There is also available much usable information on methods to control ambient temperatures, humidity, air movement, and gaseous content, with regard to both so-called comfort zones and situations outside of such zones for emergency measures.[6]

In contrast to the situation which exists in submarines, space vehicles, and hostile environments in general, it is not economically feasible to provide all of the

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1. Superscript numbers refer to items in the References at the end of this report.

sophisticated equipment needed in buildings to insure a condition of even minimal comfort during an emergency.

This project, then, is directed toward an investigation of the effectiveness of natural ventilation, without assistance from equipment and with only minor changes in existing building configuration.

1.4 SCOPE OF THE PROJECT

The scope of this project was four-fold as follows:

(1) Reliable measurement of natural ventilation. The objective of this part was to devise and to verify improved techniques for measuring rates of ventilation in spaces when the flow pattern of entering and leaving air is not sufficiently well-defined for direct measurement by conventional procedures. Tracer gas methods using both sustained concentrations and rates of decay were considered. An electronegative gas detector was evaluated and practicable limitations were determined.

(2) Replacement of air in buildings by infiltration. The objectives of this part were to study the mechanism of infiltration to determine parameters that affect air distribution and the rate of replacement of the air reservior in a building, to relate infiltration effects to restriction of occupancy in shelter spaces, and to evaluate procedures for promoting air replacement. The studies were supported

by experiments in a selected building having suitable above-ground and basement shelter spaces.

(3) Natural ventilation effects in above-ground shelters. The objectives of this part were to determine the feasibility and limitations of natural ventilation in above-ground shelters on intermediate floors of multi-story buildings, to compare the efficacy of natural ventilation effects in above-ground and basement spaces, to evaluate significant parameters, and to explore procedures for increasing rates of natural ventilation or improving distribution. The work was to include appropriate experiments in selected buildings with heat and moisture sources in shelter spaces to represent occupancy effects.

(4) Simple procedures for improving ventilation in fallout shelters. The objectives of this part were to devise expedient procedures for use of portable packaged ventilating units, to determine requirements for proper installation and air distribution, and to identify appropriate modifications of the packaged unit for optimum cost effectiveness.

1.5 GENERAL WEATHER CONDITIONS

The weather was, in general, unseasonably mild during the period of actual testing, from July 24 through August 5, 1965. It was hoped that some local extremes would exist so that limits of occupancy could be established, but such was not the case.

Outdoor dry bulb temperature varied between 59 and 87 F, wet bulb temperatures between 50 and 79 F, and relative humidity between 38 and 100 per cent. From the U. S. Department of Commerce Weather Data,[7] average daily high for the period was 79.8 F and average daily low was 58 F. At no time was the combination of temperature and water vapor even close to the extremes encountered in this area during the summer months. Weather report records for Bellefonte,[8] ten miles from State College, placed the extremes during the test period at the 86 per cent design level, which means that for 477 hours during the June to September period, outdoor conditions could be expected to exceed the average high temperature during the tests. This computation is based on a 12 hour day (from 10:00 a.m. to 10:00 p.m.). If data are based on an 8 hour day (from 10:00 a.m. to 6:00 p.m.), the figures would be 89 per cent and 432 hours respectively.

Wind direction varied, but in general conformed to prevailing wind conditions, from west to northwest. Wind velocities were quite low, varying between 0 and 17 miles per hour.

The results obtained from actual testing are of only limited practical application since they do not reflect the extreme conditions which would be imposed by severe weather.

1.6 SCHEDULING OF TESTS AND EXPERIMENTS

In order to carry out those objectives requiring building tests, it was necessary to have the use of one or more suitable buildings during a period when they were

vacant and a period in which there was a reasonable chance of encountering weather conditions which would impose a critical demand on ventilation by natural means. These conditions limited the period to the summer months on both counts, and pinpointed the period to a span of about 6 weeks of freedom from occupancy of any kind.

A further time restriction was imposed on the situation by a desire to have the use of two identical buildings so that one could serve as a control for evaluating the precise effect of external conditions while a shelter space was occupied in the test building. The closest approach possible to this requirement was the availability of two buildings practically identical in every respect except that one building was oriented 90 degrees from the other.

Although the two buildings were equipped and used by project personnel for about 6 weeks, actual recorded tests covered only a two-week period. The remaining time was devoted to the development of procedures and correction of mechanical trouble.

1.7 GENERAL PROCEDURES

In light of the objectives of this project a general plan for testing was developed. This included an effort to determine the tightness of the buildings in order to assess the infiltration characteristics of the actual construction. Reduced pressure within the building was used to determine tightness. Natural ventilation of selected shelter spaces was studied by the measurement of the decay rate of a gas injected into

the spaces, the exact process being described in later sections of this report. Generally, the flow of air within the test buildings followed a pattern illustrated schematically in Figure 1, which also explains the meaning of certain air-flow terms used throughout this report. Actually, infiltrating and exfiltrating air takes place throughout the building skin rather than in concentrated points as shown in the schematic diagram.

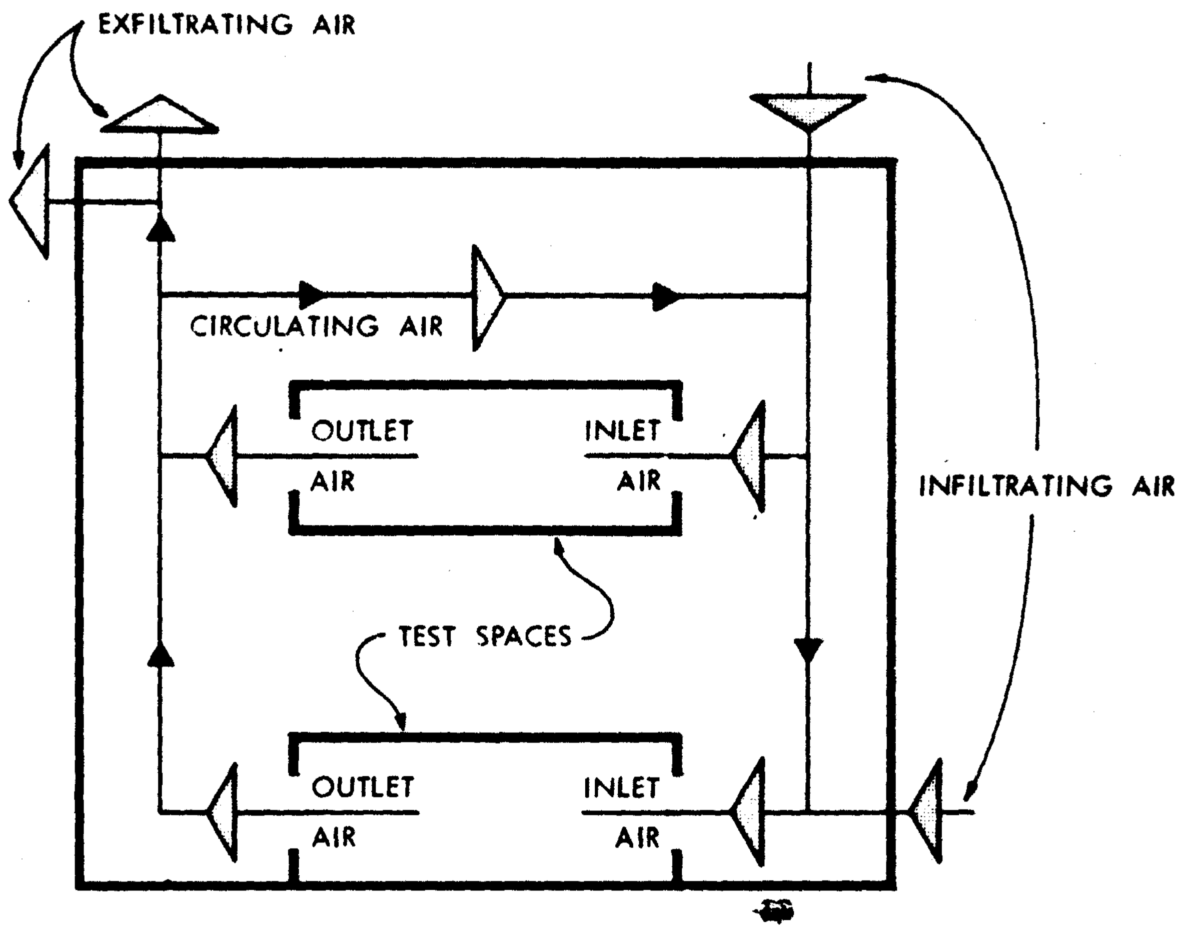


Figure 1. SCHEMATIC DIAGRAM OF AIR FLOW CIRCUIT

Basically, the process consists of moving a mass of air through one or more designated spaces without benefit of mechanical equipment. Occupants in the test spaces generate heat which in turn creates a circulation for ventilation of those spaces. Paths of air flow from test spaces to the air reservoir of the remaining volume of the building were provided to permit the heat and water vapor to be dissipated to the rest of the building or to the outside. Air from the larger volume of the building could then circulate through the test spaces. This is essentially a closed circuit which could exist only in a completely sealed building, but it is recognized that normal infiltration to the building occurs through cracks, and even to a minor extent through the wall and roof construction.

Selected test spaces were equipped to simulate occupants and to provide the correct proportion of sensible and latent heat according to space conditions. Assuming a total heat load of 400 Btu's per hour per person within the shelter spaces, this load is divided into sensible and latent losses according to dry bulb temperature by reference to Table 1. Figures in this table were derived from several sources and were presented in a recent OCD publication.[3] Simulated occupancy equipment automatically maintained the correct proportions during the progress of a test. If other than fully automatic equipment were used, Table 1 could be a guide for providing correct amounts of sensible heat and moisture to be evaporated.

TABLE 1				
RELATIONSHIP BETWEEN AIR TEMPERATURE, HEAT LOSSES AND MOISTURE EVAPORATED FOR AVERAGE SEDENTARY MAN WITH OPTIMUM CLOTHING				
Dry-Bulb Temperature	Total Heat Loss	Sensible Heat Loss	Latent Heat Loss	Moisture Evaporated
°F	Btu/Hr	Btu/Hr	Btu/Hr	Lb/Hr
40	400	350	50	0.048
45	400	350	50	0.048
50	400	350	50	0.048
55	400	350	50	0.048
60	400	345	55	0.053
65	400	335	65	0.062
70	400	320	80	0.077
75	400	300	100	0.096
80	400	270	130	0.125
85	400	220	180	0.173
90	400	120	280	0.269
95	400	20	380	0.365
100	400	-80	480	0.461
105	400	-180	580	0.557
110	400	-280	680	0.653

SECTION 2.0

MEASUREMENT OF VENTILATION RATE

SECTION 2.0 MEASUREMENT OF VENTILATION RATE

2.1 AIR VELOCITY MEASUREMENTS

One of the objectives of this project was to devise and verify improved techniques for measuring rates of ventilation in spaces when the flow pattern of entering and leaving air is not sufficiently well defined for direct measurement by conventional procedures. The direct measurement procedures included propeller-type anemometers, thermal anemometers, paper streamers, smoke patterns, etc. None of these procedures was suitable for a situation such as this because of low air velocities beyond the scope of the instrumentation, or because of confused patterns of air movement even over the area of a door opening.

An earlier study[1] investigated the use of both tracer gas methods with portable infiltration meters and a water vapor method utilizing psychrometers and applying the law of conservation of mass. At that time, the Westinghouse electronegative gas detector was examined and used for a short time with the tentative conclusion that it offered many advantages over all other methods investigated. This present project concentrated on the application of that instrument for measuring the relatively low rates of air change encountered in natural ventilation.

2.2 TRACER GAS METHODS

In using a tracer gas to determine the ventilation of a building, a choice exists of using either a sustained rate of injection or a concentrated injection followed by the measurement of rate of decay. Both methods were used in this project.

2.2.1 SUSTAINED RATE OF INJECTION

When a tracer gas is injected into a fixed volume at a known rate and well mixed with the air, the resulting concentration increases steadily. If, however, air free of any tracer gas is introduced into the space and an equal quantity of air-tracer gas mixture is removed or permitted to escape, the concentration increases at a slower rate until an equilibrium concentration is established at which as much tracer gas escapes with the exiting air as is introduced by injection. When an inert tracer gas is used, without absorption or other reactions, the factors needed to calculate a ventilation rate are the volume rate of injection of the tracer gas and the volume concentration of the gas in the space after the equilibrium condition has been attained. The volume of gas-free air entering the space can then be calculated, and by comparison with the volume of the space, the air change rate can be determined.

The procedure used in this research project incorporated several features which enhanced the results. The tracer gas was admitted at six separated locations near the top of each test space, or in the case of multi-story observations near the ceiling of each story. Diffusion of the gas and natural air convection provided a good mixture of the gas throughout the space. The air sample for analysis was drawn off at six locations near the floor. The injection and collection locations were distributed throughout the space to obtain uniform conditions. The tracer gas was first mixed with compressed air and the larger volume flow permitted the use of relatively large pipe so that dirt accumulation and partial clogging could not occur.

The tracer gas was metered in two ways to check the actual amounts used. The cylinder of compressed tracer gas was placed on a platform scale that permitted weighing of the amount used in a given time. A gas regulator reduced the pressure to near atmospheric to permit the use of a Fischer and Porter Flowrator to monitor the rate at which the gas was being injected. Standard procedures were used to convert the flowrator readings to volumes of gas. Known characteristics of the gas permitted calculations for comparing the indicated flowrator volumes with the scale weight observations; it was determined that very good agreement existed between the two methods.

The gas detector had good sensitivity so that a moderate concentration of 10 to 30 ppm was sufficient to provide required data. Consider, for example, a typical test result shown by the solid line in Figure 2, in which the fifth floor shelter space has an effective volume of 48,100 cubic feet. If there were one million cubic feet of space and one cubic foot of gas were injected, the concentration would be one ppm. Therefore, for the actual shelter volume with one cubic foot of gas injected, the concentration is $\frac{1,000,000}{48,100}$ or 20.8 ppm. For an injection of 0.829 cubic feet per hour (the actual amount used in the test), the concentration is 0.829 x 20.8 or 17.3 ppm. This represents the expected concentration if there were one air change per hour. Since only 10 ppm of SF_6 was measured for test 14B, indicated on Figure 2, an air change rate of $\frac{17.3}{10}$ or 1.73 results.

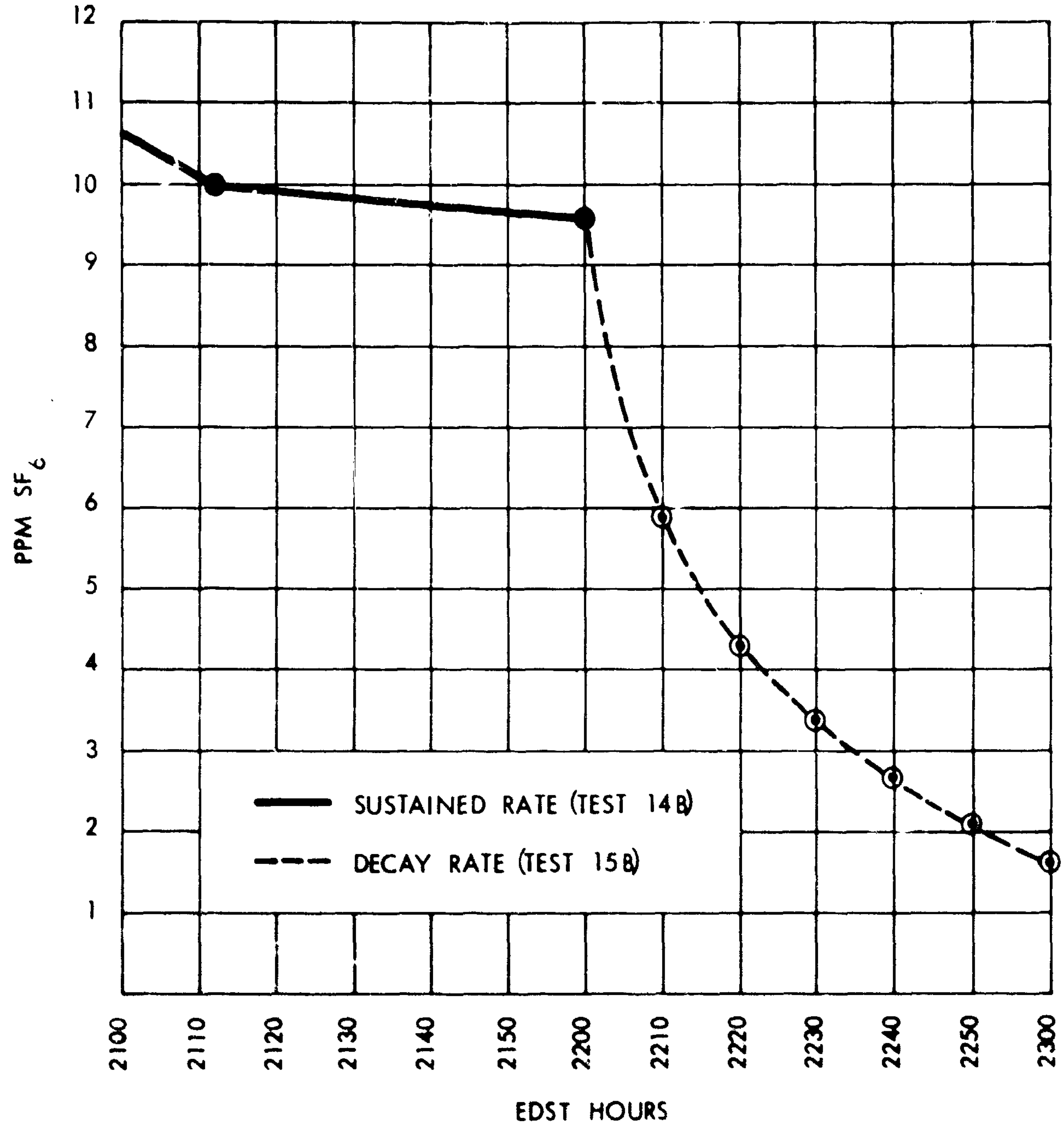


Figure 2. COMPARISON OF GAS INJECTION METHODS

2.2.2 DECAY RATE

The rate of decay method for determing air infiltration utilizes the relationship in which the change in gas concentration is equal to the tracer gas leaving the space with the outlet air in the same period of time. Expressed mathematically, this is:

$$-dC = NC\,dt \tag{1}$$

where C = concentration of tracer gas at time t

N = number of air changes per hour

t = time

with $C = C_o$ at $t = 0$, equation (1) becomes:

$$N = \frac{\log_e C_o/C}{t - t_o} \tag{2}$$

The procedure used was to inject a quantity of tracer gas into the space at such a rate and in such a manner to achieve a uniform concentration of 35 to 50 ppm in as short a time as possible. The test equipment permitted injecting sufficient gas within a 20 minute period to attain this concentration. Injection was stopped and the concentration of the gas monitored. When the concentration was plotted on the log scale and time plotted on the rectilinear scale of semi-log paper, the resulting curve indicated the rate of air change. A straight line shows that the air change rate is constant. The process is more fully explained and illustrated in the Appendix.

Figure 3 is a replot of the dash line portion of the curve shown in Figure 2, using semi-log paper instead of uniformly spaced coordinates. This is a typical test,

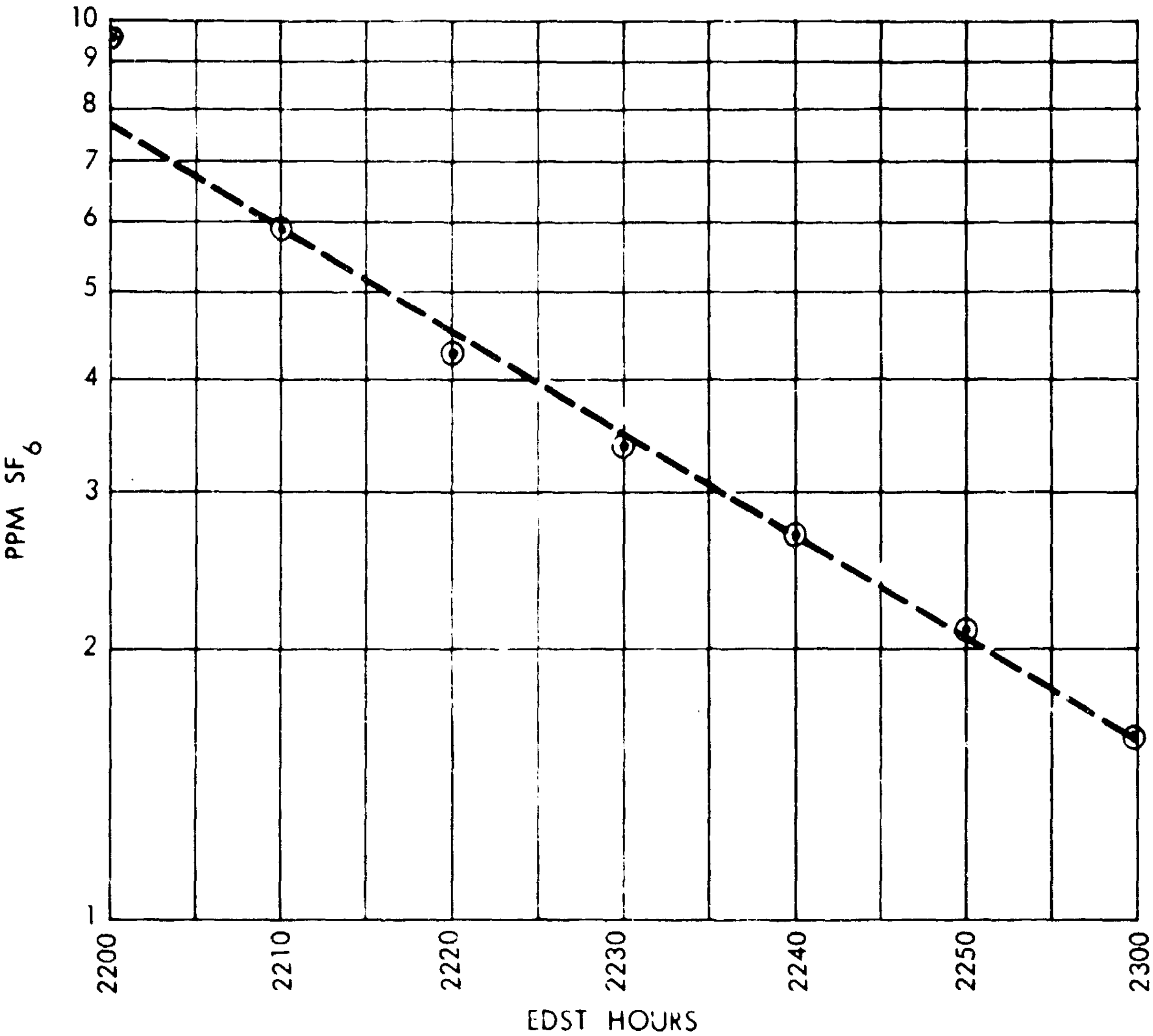


Figure 3. DECAY RATE OBSERVATION — TEST 15B

No. 15B, showing results of the decay rate method. In this example,

$$\frac{\log_e 7.7\ \text{ppm}/1.6\ \text{ppm}}{1\ \text{hour}} = 1.58$$ air changes per hour. This represents substantial agreement with test 14B (using sustained rate method) which had identical conditions and which preceded test 15B by only a few minutes.

2.3 AIR SAMPLING EQUIPMENT

The limited time period during which testing was possible required a carefully developed gas distribution system. Time limitations made it necessary to run tests semi-automatically 24 hours per day. Furthermore, it was necessary to check air change rates in many different locations at one time, to provide automatic monitoring and recording of data, and to permit the injection of tracer gas to any location in either of two test buildings by remote control from a central location. To accomplish all this, a tracer gas distribution system was designed, along with a sample collection system which allowed great flexibility along with a high degree of reliability.

Basically, both the gas injection and air sample collection systems utilized one-half inch diameter polyethylene pipe of the type common in home and farm water systems. This pipe was chosen for its felxibility and low cost, along with its ready availability in the large quantities (8000 feet) needed for this project. Other requirements satisfied by this pipe were: low resistance to air flow, availability of standard fittings, and ease of workability. The pipe proved satisfactory in every respect, and is highly recommended for this type of work.

To serve as the sample collection system, a length of this pipe was run from each floor of each building to the control center. Figures 4, 5 and 6 show the pipe running out of one building, draped to the walkway roof, and running across that roof to the other building in which the central control room was located. On each floor, six rigid plastic tubes, 1/16 inch diameter and 2 inches long, Figure 7, were inserted into the polyethylene pipe by drilling a small hole in the wall of the pipe

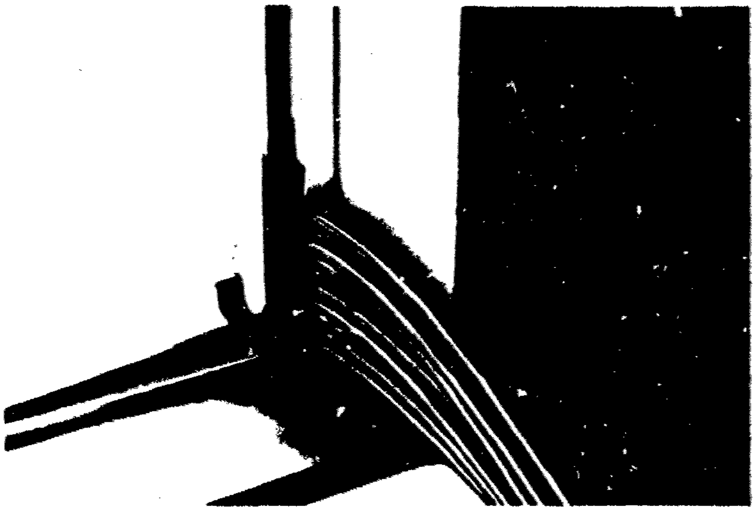


Figure 4.
PLASTIC PIPE THROUGH WINDOW OPENING

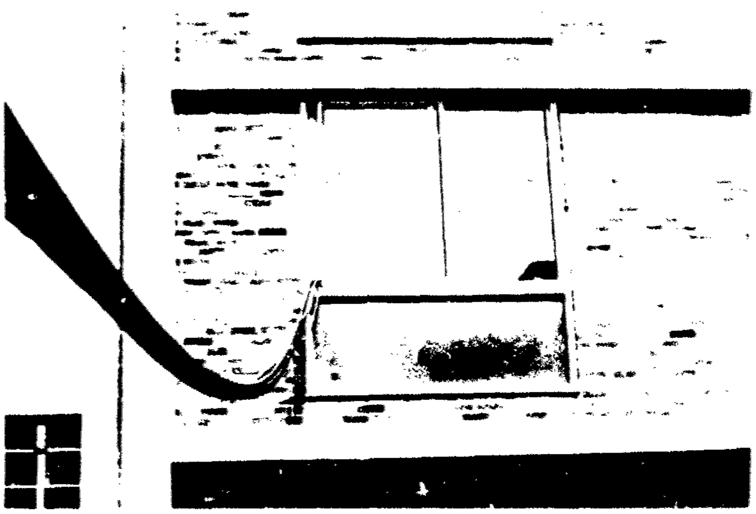


Figure 5.
PLASTIC PIPE SUSPENDED BETWEEN BUILDINGS

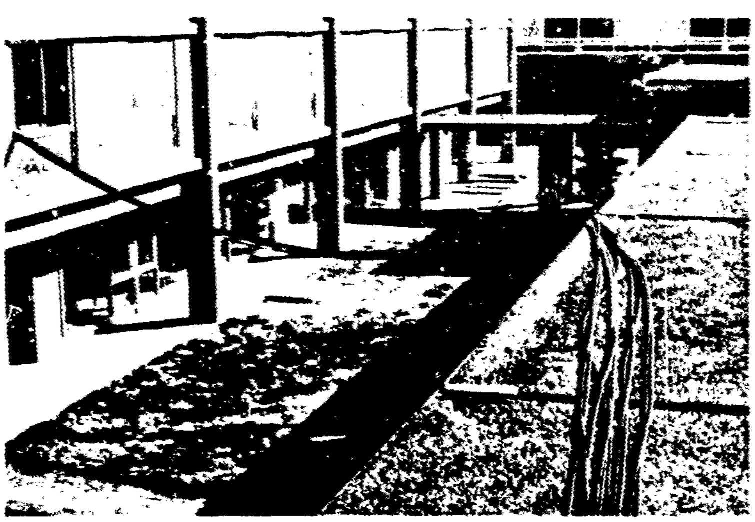


Figure 6.
PLASTIC PIPE ON WALKWAY ROOF

and forcing the tubes into place. These very small tubes were used to provide equal air samples from all locations in both buildings, since the total resistance of a run was affected by the length of the tube and, therefore, different lengths of pipe to various floors could be balanced in resistance. A pipe carried the collected sample back to the central control room, Figure 8, and connected to one position on the automatic multi-valve, Figure 9, which enabled the operator to monitor that pipe at will.

Figure 7.
TUBE OUTLET IN
PLASTIC PIPE

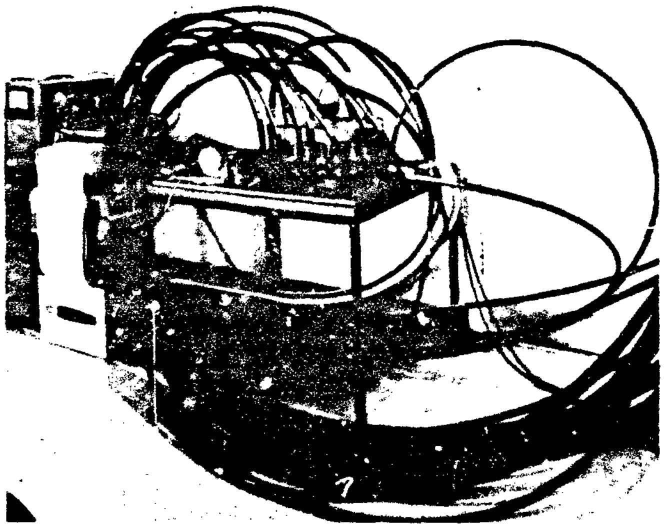


Figure 8.
PLASTIC PIPE TERMINATING
IN CONTROL ROOM

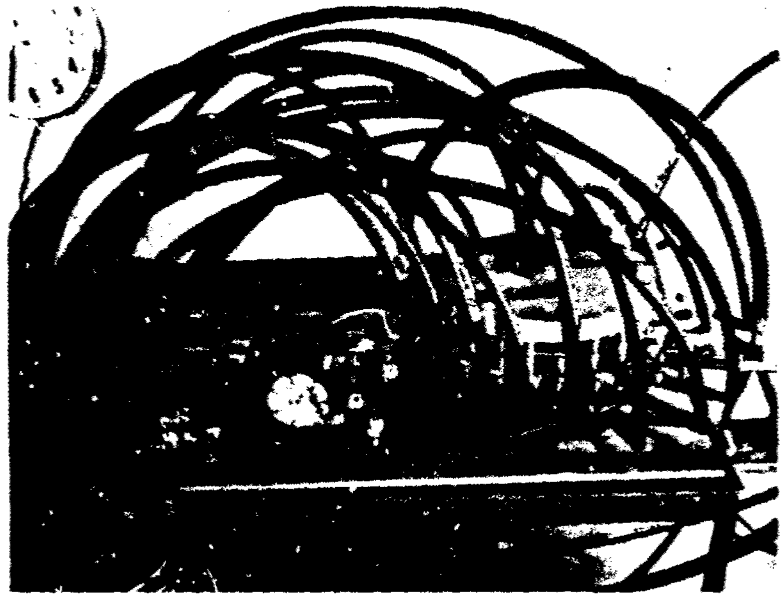


Figure 9.
THE AUTOMATIC MULTI - VALVE

A schematic of the Automatic Multi-valve is shown in Figure 10 below.

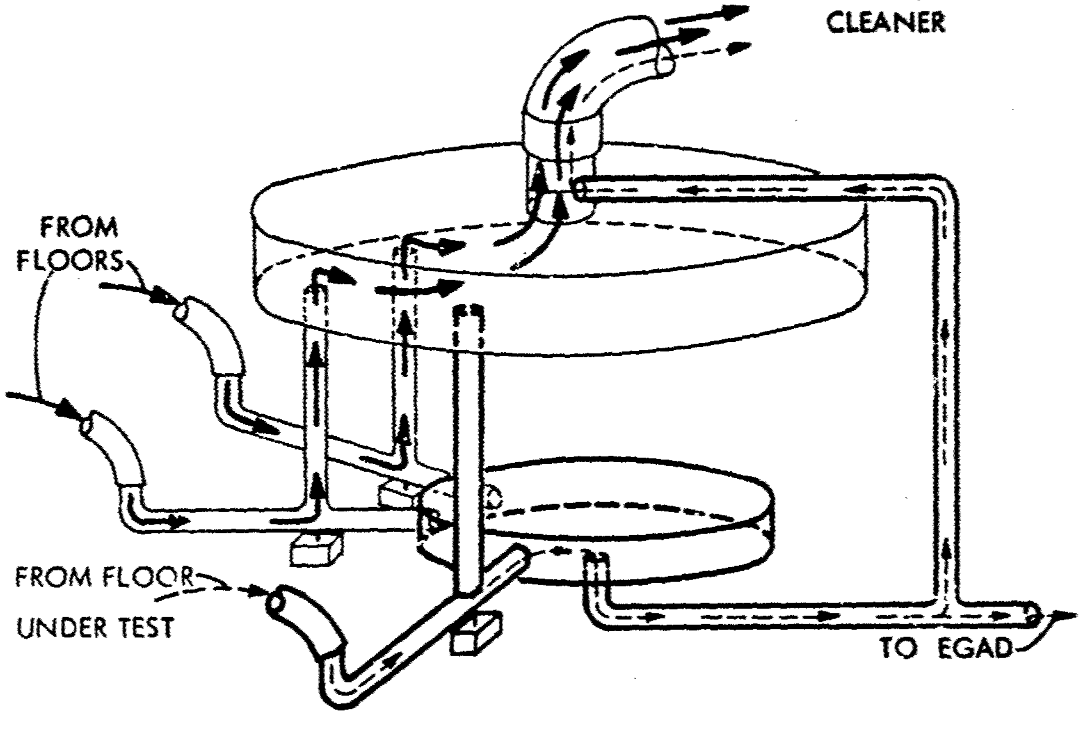


Figure 10. SCHEMATIC OF THE AUTOMATIC MULTI - VALVE

The automatic multi-valve is a device developed specifically for this project to permit continuous fresh samples to be drawn from each floor. The samples can then be checked for concentration of tracer gas. The device contains twenty electrically controlled three-way valves arranged in a circle around two chambers. Each valve is normally open to the upper chamber, allowing air from the connected floor to be drawn off continuously, which maintains a fresh sample of air from each floor at the control room location. Figure 11 is a schematic layout of the valving arrangement showing air movement to the upper chamber.

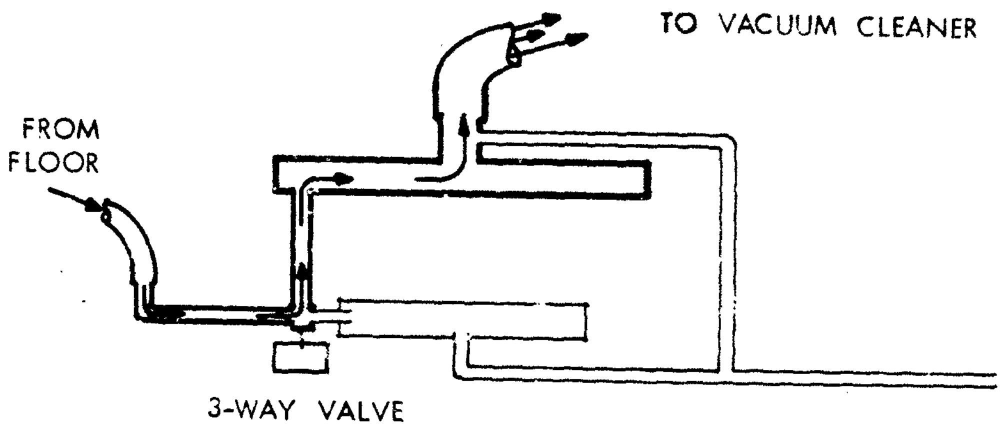


Figure 11. AIR TO UPPER CHAMBER

An industrial shop vacuum cleaner, Figure 12, was used to remove the air from the upper chamber which then passed through the vacuum cleaner and was discharged to the exterior of the building.

Figure 12.
INDUSTRIAL TYPE
VACUUM CLEANER
(ON RIGHT)

A switching mechanism, shown in Figure 9 to the left of the automatic multi-valve, was constructed to switch, in sequence from 1 to 20, the air flow from the valves to the lower chamber. It was initially thought that the gas detector equipment would require three minutes to detect and stabilize on a gas sample. This would permit 18 locations to be sampled in 1 hour. The additional valves were used to monitor fresh outside air for recalibration of the detector every 30 minutes.

When a valve is switched on, the sample from the location it is monitoring is sent to the lower chamber as shown in Figure 13.

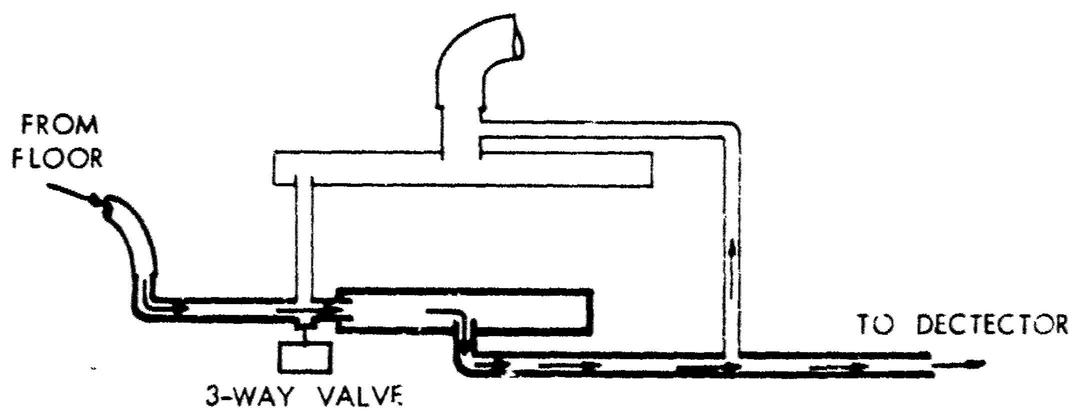


Figure 13. AIR TO LOWER CHAMBER

The lower chamber is swept free of its air by the same vacuum system which continuously clears the upper chamber. Part of the sample is also taken by means of a small vacuum pump and routed to the detector equipment.

The pattern cycle of air travel may be summarized as follows:

Normal: Air is collected from six locations on each floor and is then purged through the upper chamber and discharged outside the building.

For 3 minutes of every hour: Air is switched to the lower chamber and some is drawn off through the vacuum pump and sent to the detector equipment.

Recalibration: For recalibration, fresh outside air is necessary. Each time valve #10 or #20 is opened, fresh air is directed through the lower chamber to the detector. A special switch is also closed, via a relay which starts the automatic recalibration built into the detector equipment.

The air sampling system of plastic pipe with inserted short tubes worked very well; however, a few minor modifications should be made to the multi-valve. It was often desirable to monitor positions in a sequence other than 1 to 20, and it was frequently necessary to eliminate a number of positions. If, for example, a sequence of 1 - 4 - 5 - 6 - 7 - 9 - 10 was desired, much hand switching was necessary. This required close attention to the controls and consumed a high percentage of operator time. A more flexible system could easily be built into this electronics arrangement for future use. It was also discovered that the detector would respond and stabilize in only one minute instead of three, making a one minute time for each floor more desirable. This time reducation would allow more samples to be

taken in a given time period which, in turn, would probably increase accuracy and reliability of data. However, three minutes are still necessary for accurate recalibration. Therefore, two timers would be an improvement, one for one-minute samples from the floors, and a three-minute timer for fresh air samples.

The tracer gas used for this project was sulphur hexafluoride (SF_6) because the Westinghouse electronegative gas detector, abbreviated EGAD and shown on the left in Figure 14, is most sensitive to this gas. It was desired to have a flexible distribution system which would evenly distribute gas to and around each floor space. The same type of one-half inch diameter polyethylene pipe used for the air sampling equipment proved to be a most satisfactory solution in every respect.

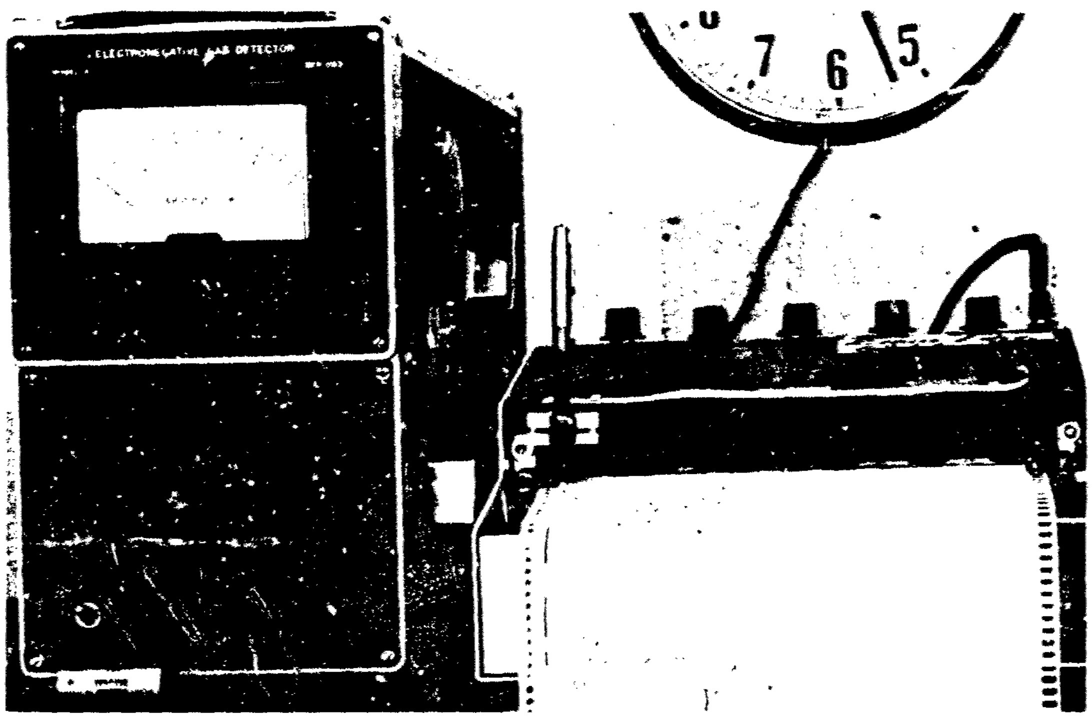


Figure 14. THE ELECTRONEGATIVE GAS DETECTOR AND SERVO CHART RECORDER

The tracer gas, SF_6, was delivered in cylinders each containing approximately 120 pounds of gas. Cylinder weights were recorded to the nearest once at the beginning and end of each test, see Figure 15, and at intervals of approximately 1 hour if a long test was in progress. The gas was passed through a pressure reducing valve (Haris regulator, Model #92-45) with which flow rate could be controlled quite accurately for relatively long periods of time without need for continuous resetting. Gas volume was easily checked on a calibrated flow rate tube, shown on the wall in Figure 15, before it was passed into the dilution and distribution system. It was decided to dilute the SF_6 with air prior to distribution, since only small quantities of the tracer gas were required, and mixing on the floor under test would likely be poor if a pure gas sample were used. Air for dilution was provided by a small one cylinder air compressor set to run with almost free discharge, from two to ten inches of water. Gas was injected into a tee between the output of the air compressor and the distribution system. The distribution system on each floor consisted of the plastic pipe with six 1/16 inch diameter tubes identical to those in the collection system. The tubes were located near the ceiling to separate the distribution outlets from the collection tubes located near the floor, which insured good mixing of the tracer gas with the air in the test space. Figure 16 shows the distribution and collection pipe in the corridor on one of the floors.

The time necessary for detection of gas concentration using this distribution and collection system varied with the distance of the test space from the control center,

but in no case was more than 5 minutes. This time requirement included total time from the start of gas injection flow to the indication by EGAD of SF_6 contamination in the space.

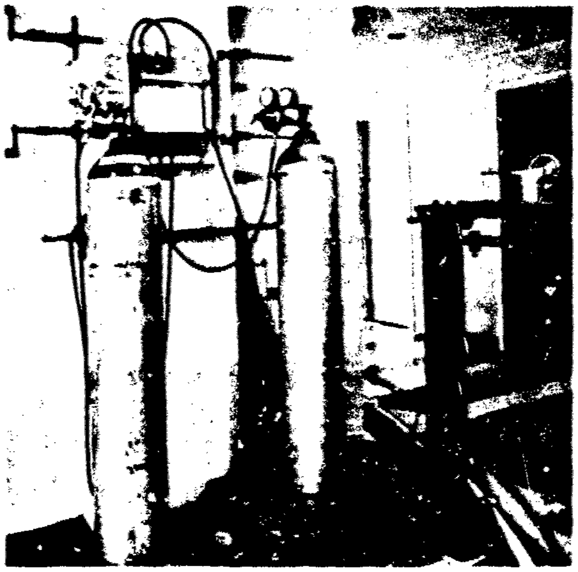


Figure 15.
GAS CYLINDERS

Figure 16.
DISTRIBUTION AND COLLECTION PIPE

2.4 ELECTRONEGATIVE GAS DETECTOR

The Electronegative gas detector (EGAD) is a device manufactured by Westinghouse for detecting leaks in gas filled electrical equipment. Figure 17 is a schematic diagram of the major parts of the EGAD.

EGAD had several pecularities which proved to be annoying, time consuming, and sometimes difficult to correct.

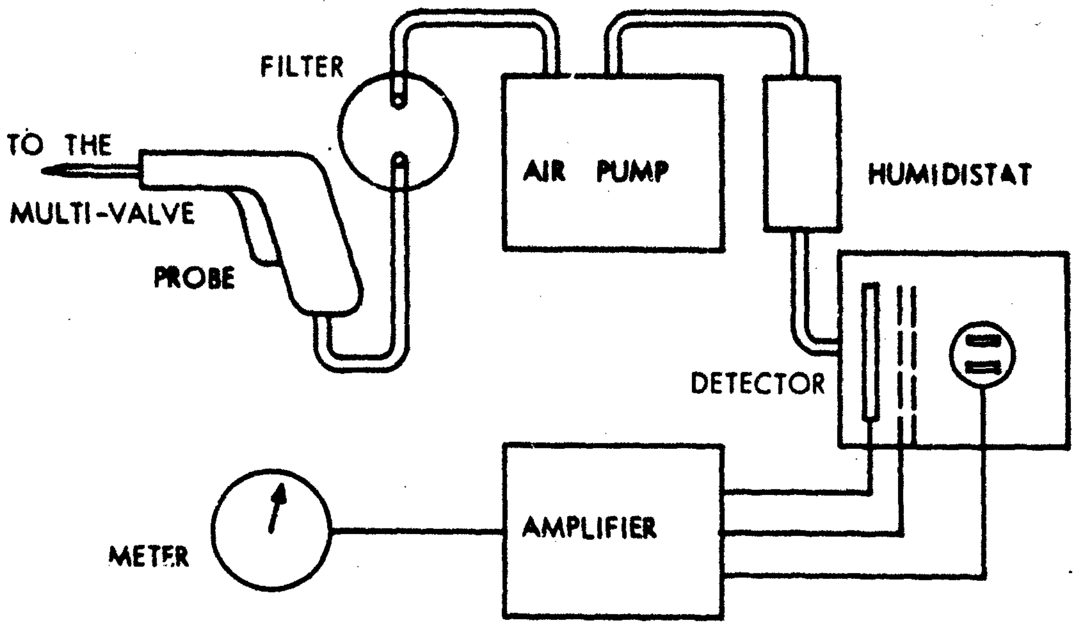


Figure 17. SCHEMATIC DIAGRAM OF EGAD

A Westinghouse Odorout ozone lamp was used in part of the detection apparatus. When this lamp approached the end of its usable life, an indicating light on the front panel dimmed and flickered, and output became erratic. Calibration also became unstable and at times even impossible to achieve. The life of this lamp was only 20 to 30 hours, and time necessary for stabilization of a new lamp varied between one and four hours. Thus, much time was spent in replacing lamps and recalibrating the instrument. Also, Odorout lamps were not locally available. However, another ozone lamp made by Westinghouse called Sterilamp was available. Even though these two lamps looked the same in all respects, Sterilamp performance was unsatisfactory. Eventually, a General Electric Ozone lamp was tried in the equipment, and was found to stabilize rapidly with a service life of upwards of 100 hours.

Another difficulty with EGAD arose when an attempt was made to calibrate the equipment using a plastic drum filled with fresh air and injecting a known quantity of SF_6 into it. It was found that no agreement could be obtained between original Westinghouse calibration and calibration during this project. Furthermore, it was not yet possible to duplicate calibration twice in a row. After much experimentation, it was found that internal air leaks in the instrument were causing an improper zeroing operation as well as diluted samples, which further reduced accuracy. The leaks were on the vacuum side of the EGAD air circuit and were almost impossible to eliminate. It was decided that if the entire internal air circuit were pressurized, all leaks would be outward and therefore would not change the calibration of the instrument. Pressurization was accomplished by placing a small diaphram vacuum-pressure pump in the line before EGAD and pressurizing the entire piece of equipment. This technique worked very well. The method of checking for instrument leaks was to cover EGAD with a large plastic bag and inject SF_6 into the bag. If any leaks were present they would be detected on EGAD and show up as a meter indication. After pressurization of the equipment, no leaks were detectable.

After the leaks were corrected, proper calibration was accomplished with a plastic drum which contained a small electric mixing fan. Two small holes were placed in the top of this drum. One was used for removing a sample from the drum for EGAD, the other for injecting accurate amounts of SF_6 to the drum. Injection was made in 0.5 cc amounts with a calibrated syringe while reading meter deflection and servo chart recorder deflection until full scale was reached on the EGAD.

This had to be done rapidly as decay was taking place at the same time injection was being performed.

This problem of leakage caused the initial series of tests and calibrations to be invalid, creating an additional burden on the remaining time available for testing.

The response of the EGAD was non-linear as Westinghouse had advised. For example, on the 50 ppm scale, which was used exclusively, 40 ppm indicated equaled 53.2 ppm calibrated, and 50 ppm indicated equaled 100 ppm calibrated. The most accurate part of the 50 ppm scale was from 0-30 ppm, calibrated values being off by less than 2 ppm from indicated value. Figure 18 is the calibration curve used for this project.

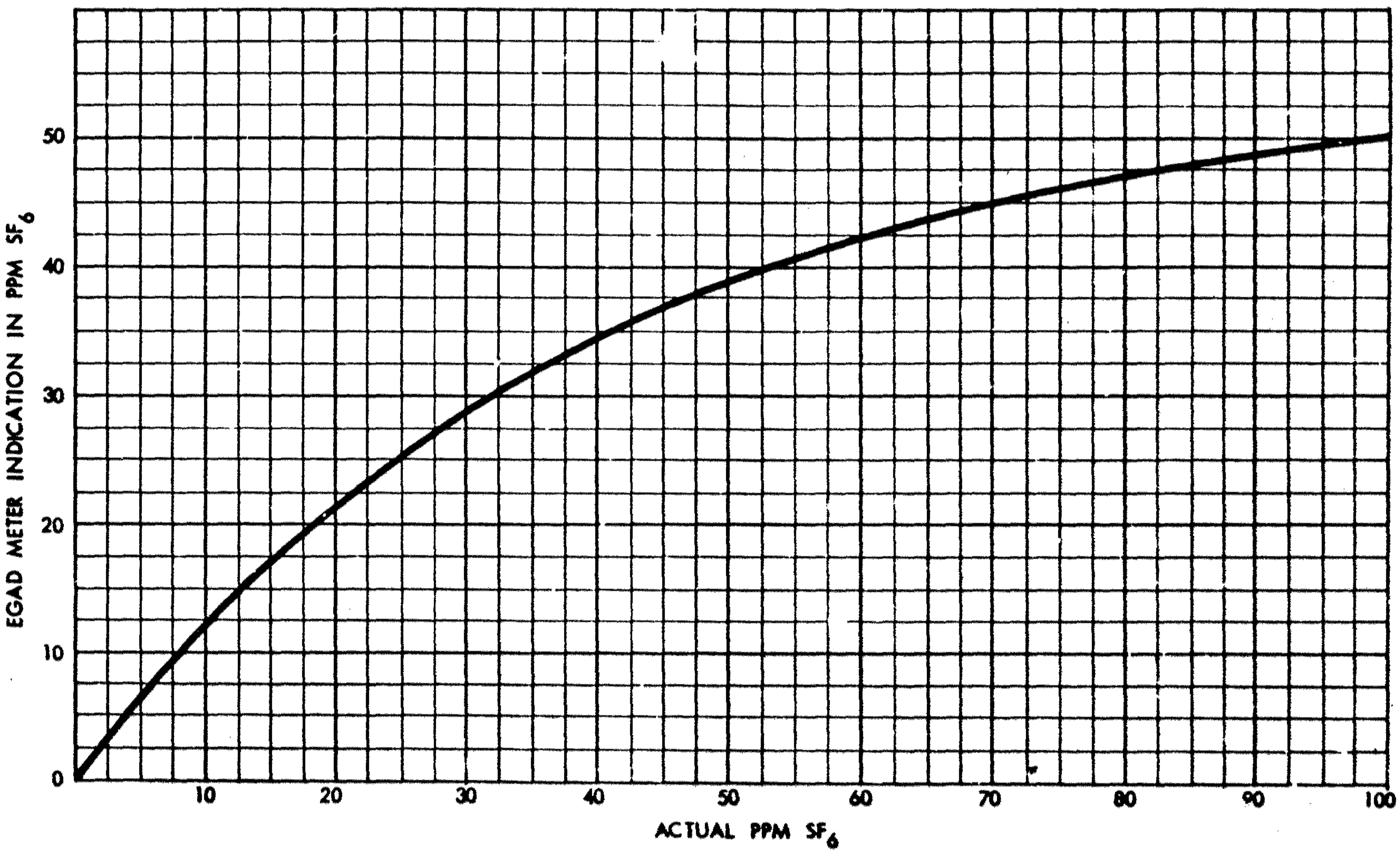


Figure 18. EGAD CALIBRATION CURVE AT 50 PPM FULL SCALE

SECTION 3.0

INFILTRATION OF AIR IN BUILDINGS

SECTION 3.0 INFILTRATION OF AIR IN BUILDINGS

3.1 MECHANICS OF INFILTRATION

Infiltration may be defined as air movement inward through cracks, interstices around windows and doors, and through the walls and other exterior constructions of a building. Exfiltration can be defined as flow out of a building through cracks, interstices, and constructions. Natural ventilation depends upon two things: pressure differential between the inside of a building and the outside, and the resistance to flow of air offered by openings, cracks, and interstices. The pressure differential, on the other hand, is caused by either or both of the following: (1) a difference in density of air between the inside and outside, and (2) wind pressure.[6]

3.2 PARAMETERS AFFECTING INFILTRATION

Many factors affect the rate of infiltration and exfiltration in a building. Some of these have been explored in detail by numerous researchers in past years. Others have been recognized but not determined accurately either by theoretical calculation or in the laboratory. Variations in actual construction between two seemingly identical buildings and unpredictability of weather conditions indicate the futility of attempting to arrive at a precise answer by calculation.

Nevertheless, there is some advantage to be gained by at least recognizing the influences which are involved. The more obvious ones are as follows:

ITEMS DEALING WITH EXTERNAL WEATHER CONDITIONS:

(1) Siting and orientation of the building
(2) Wind velocity, direction and constancy
(3) Relationship between positive and negative pressures on building walls
(4) Ambient temperature conditions - magnitude
(5) Solar heat conditions on the building and its various parts
(6) Barometric pressure conditions
(7) Precipitation - kind, magnitude, duration

ITEMS CONCERNING EXTERIOR SKIN CONSTRUCTION OF THE BUILDING:

(i) Wall, roof and floor construction - porosity, mass, texture, color
(2) Cracks in operable windows and doors
(3) Cracks between components and construction
(4) Cracks in joints and materials

ITEMS DEALING WITH INTERNAL BUILDING CONDITIONS:

(1) Presence of flues or stacks such as stair wells, elevator shafts, vertical pipe chases, etc.
(2) Height and size of stacks
(3) Mechanical ventilation - amount, kind and distribution
(4) Heat generation sources
(5) Porosity of interior surfaces of exterior walls
(6) Doors - locations, size, tightness and position
(7) Ceiling heights

The considerable number of influencing factors would be sufficient to emphasize the need for assessing conditions in actual buildings and to seek results which would be immediately helpful for predicting natural circulation possibilities under sets of

given circumstances. Insofar as time and facilities permitted, the present study considered these influences.

3.3 PROCEDURES FOR ACCELERATING INFILTRATION

Several devices can be used to accelerate infiltration in a building:[9,10,11] windows and doors can be opened on both windward and leeward sides; skylights or hatches can be opened at the tops of exhaust stacks; additional heat sources can be used at the bottom of an exhaust stack;[12] mechanical ventilation, operated manually or with power equipment, can be employed to enhance air movement; and people and other heat generators can be concentrated and located in such positions as to increase lateral movement of air between stacks.

All available devices deserve consideration in any effort to accelerate infiltration in lieu of forced ventilation.

3.4 REQUIREMENT OF INFILTRATION RATE TO SHELTER OCCUPANCY

Numerous studies have been made concerning the quantity of fresh air required for human occupancy in a building space and the effects of extreme overcrowding.[2] The minimum quantity needed by occupants is related to the maintenance of both a satisfactory quality and a tolerable temperature-humidity (or effective temperature) condition. The frequently used figure of three cubic feet per minute per occupant will in all ordinary circumstances insure satisfactory quality of the air, but only under the most favorable conditions will it keep the temperature-humidity level within a tolerable range. The upper limit has been generally set at 85 F effective temperature.

The infiltration rate will, therefore, have a very direct relationship to the permissible shelter population density. For shelter planning, it is desirable and even imperative to be able to determine the maximum number of people that a given space can accommodate under stated climatic conditions and under stated ventilation rates. It is axiomatic that the shelter population density must decrease as the ventilation rate decreases if the shelter occupancy is initially at maximum density.

3.5 POSSIBILITY OF FALLOUT PARTICLE INFILTRATION

Whenever air infiltrates a building there is a possibility of a particulate matter entering along with the air. The quantity of the entering particulate matter depends primarily upon its size and density, wind direction and velocity, and upon the velocity of the entering air. Size of crack or opening is a determining factor as demonstrated by a series of tests conducted on models in a low speed wind tunnel and using a distribution of simulated fallout particles.[13] This present study deals basically with a closed, but not sealed, building. The admission of dangerous quantities of fallout particles under these conditions is highly unlikely. Even if a limited number of windows are opened where they are most effective in accelerating internal air movement, the safety of designated interior shelter spaces would not be changed materially.

3.6 AIR FLOW DUE TO TEMPERATURE DIFFERENTIAL

A stack or chimney effect will occur in a building when the temperature inside the building is higher than that outside, the pressure difference occurring as a result of air density difference. This action, of course, is dependent upon the presence of

vertical stacks such as air shafts, stairs, or elevator shafts. If the internal temperature is greater than the outdoor temperature a negative inside pressure and an inward flow of air will occur at lower levels. There will be a positive inside pressure and an outward flow of air at higher levels. A neutral zone will normally occur at some intermediate level. This is the zone where there is no pressure differential between the interior and exterior. The neutral zone will not necessarily occur at the vertical midpoint. An excellent discussion of this chimney effect is to be found in the ASHRAE Guide and Data Book.[6]

The air flow due to temperature differential can be determined by the following well known equation:

$$Q = 9.4\,A \times h(t_i - t_o) \quad \text{in which:}$$

Q = Air flow in cfm
A = Free area of inlets or outlets (assumed equal) in square feet
h = Height from inlet to outlet in feet
t_i = Average temperature °F of indoor air in the height h
t_o = Average temperature of Indoor air °F

9.4 = The constant of proportionality including value of 65% for effectiveness of openings (reduced to 7.2 for unfavorable conditions)

The above equation is applicable only if there is no significant resistance to flow within the building between inlets to outlets. This condition will not exist in an occupied space. The importance of maintaining the greatest possible height h is obvious, in order to produce the maximum air flow. Opening a window low down on the inlet and near the top of the outlet will also increase the effectiveness of air flow. This, too, is obvious from the equation. The remote possibility of entry

of fallout particles may prompt one to delay opening windows until the particles have stopped falling.

3.7 AIR FLOW DUE TO WIND FORCES

Air flow within a building, or the creation of a pressure differential, can be attributed in part to the wind. Important parameters concerning the flow due to wind are: wind velocity, wind direction, seasonal and daily variations in velocity and direction, local wind interference by nearby buildings and other man-made structures, and interference by hills and other natural obstructions. In regard to wind forces, the statement is made in the ASHRAE Guide and Data Book[6] that "in general — velocity of wind acting on the surface of a building is too complicated to be represented by anything that is rational". The shielding of one building by another usually results in significant reductions in effective wind velocities. In spite of all the uncertainties, it is possible to develop some rough boundary conditions provided one can accumulate certain pertinent data. Further research and investigation is needed in this area.

In general, pressures will be positive on the windward side and negative on the leeward side. Pressures on the remaining sides may be either positive or negative depending on the angle of the wind. Static pressure patterns on the roof depend upon the roof type; whether flat, low pitched, or high pitched. Negative pressures will generally exist on flat or low pitched roofs, and positive pressures on high pitched roofs on the windward side and negative pressures on the leeward side. The static pressures on surfaces of buildings are approximated by the following relationship

based on air density of 0.075 pounds per cubic foot.

$$PV = 0.000482 V_w^2 \quad \text{in which:} \tag{3}$$

PV = Velocity head in equivalent inches of water
V_w = Wind velocity in mph

Air flow due to wind can be expressed as:

$$Q = EAV \quad \text{in which:}$$

Q = Air flow in cubic feet per minute (4)
E = Effectiveness of opening,
0.50 to 0.60 for perpendicular winds
0.25 to 0.35 for diagonal winds
A = Free area of inlet openings in square feet
V = Wind velocity in feet per minute, or:
fpm = miles per hour x 88

The summer wind velocity is usually lower than the winter velocity and the summer wind direction is different from the winter direction in about 2/3 of the localities for which we have records. It is reasonable to design for 1/2 of the average seasonal velocities which can be procured from weather reports. However, caution should be used in shelter planning because calm periods, if extended, would present a most severe condition.

As a direct assistance in the present study, when one considers the opening of windows and doors in order to facilitate circulation, the following points should be kept in mind: Inlets should be advantageously located with respect to the wind, ideally facing directly into the prevailing wind. For best results outlets should be in one of five places: (1) on the side directly opposite to the prevailing wind, (2) on the roof

in a low pressure area caused by the jump of the wind, (3) on the side adjacent to the windward face where low pressure areas occur, (4) in a monitor on the side opposite from the wind, or (5) in roof ventilators or stacks.

SECTION 4.0

THE TEST BUILDINGS

SECTION 4.0 THE TEST BUILDINGS

4.1 WALL AND FLOOR CONSTRUCTION

Buildings used for this project are located on the University Park campus at State College, Pennsylvania. Both buildings are identical in design and construction. Each is an eight-story dormitory with full basement, completed in 1961. The frame and floors are constructed of reinforced concrete. Exterior walls are composed of 4" brick, 2-3/4" air space, and 8" stone aggregate concrete block. Spandrals under windows consist of 1" metal curtain wall, air space, and 8" concrete block with concrete filled cores.

Floor slabs are waffle plate construction with 3-1/2" concrete over 8" deep forms. Roof construction is the same as floors, but topped with 1-1/2" insulation and built up roofing.

Construction throughout is somewhat above average with respect to tightness so that infiltration and exfiltration through metal window cracks and masonry walls are a minimum. Windows are aluminum sliding type, of single sheet double strength window glass. All windows have pile weather-stripping and were kept closed during tests. There were no draperies at any of the windows. Window openings are 6'-1" x 6'-11". On the long sides of the building, window area is approximately 25% of total wall area.

4.2 BUILDING ORIENTATION

The plan relationship of building A to building B and the location at other buildings, construction in progress, parking lots, and walks are shown in Figure 19. It is interesting to note that no shadows were cast by either building on the other at any time during the period of testing. The photograph, Figure 20, shows the two buildings looking directly west with the building B on the left and building A on the right. Covered walkways between the buildings are also shown. Figure 21 is a photograph of the two buildings looking directly east. Building B is casting a shadow on building A in this photograph only because the picture was taken some months later in the year, after testing was completed.

Wind patterns were influenced to some extent by adjacent buildings, but since most of the other buildings were either well removed from the test structures or considerably lower, that influence was minimal, particularly above the second or third story.

4.3 FLOOR PLANS

Floor plans of both test buildings are shown in Figures 22, 23 and 24 and a roof plan in Figure 25. Simulated shelter areas are noted by cross-hatching on the appropriate plans. Locations of equipment and tracer gas release and collection points are also indicated.

4.4 SECTIONS

A longitudinal cross section through the entire building is shown in Figure 26 and a transverse section in Figure 27. Again, simulated shelter spaces are cross-hatched.

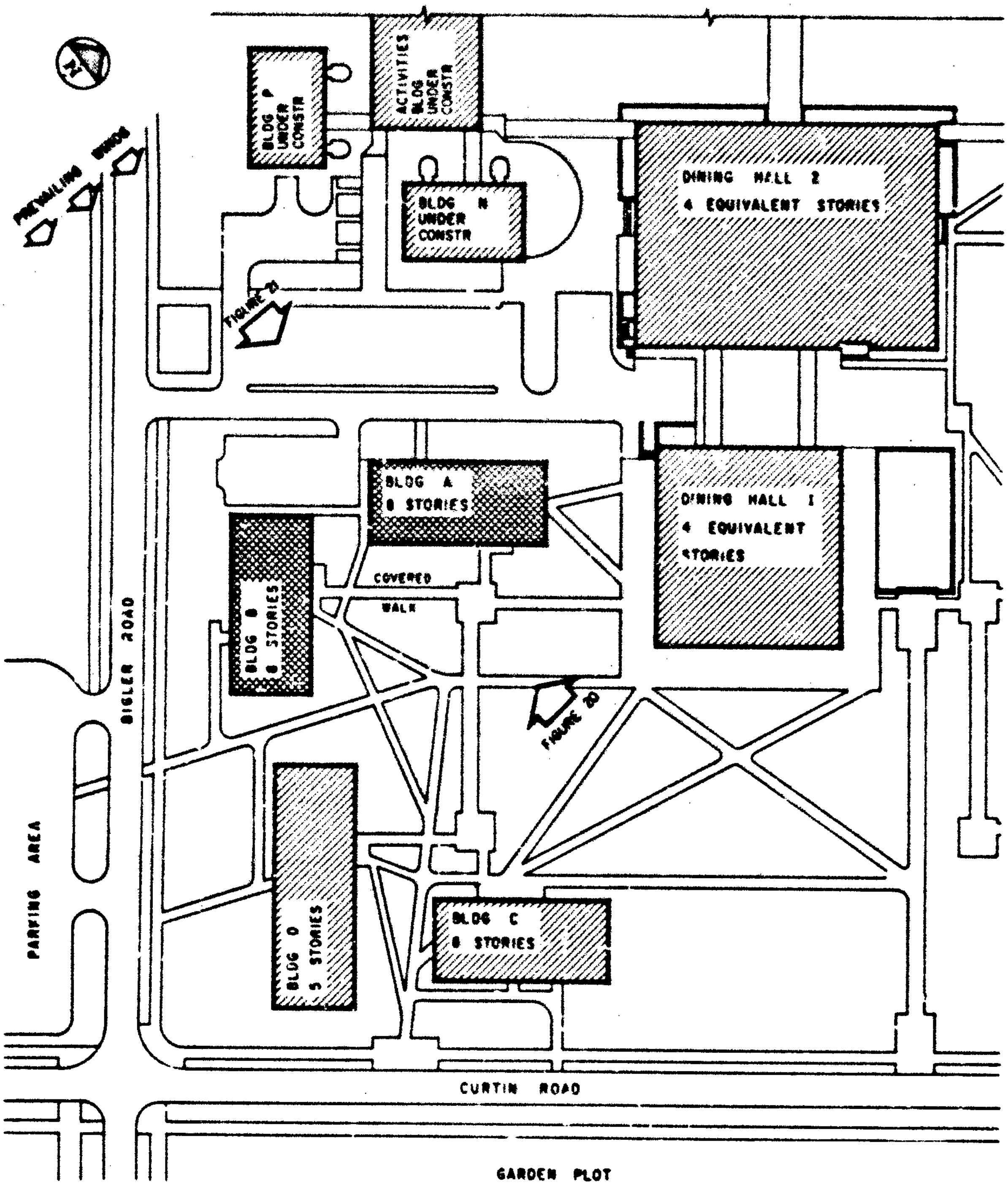


Figure 19. PLOT PLAN

0' 50' 100' 200'

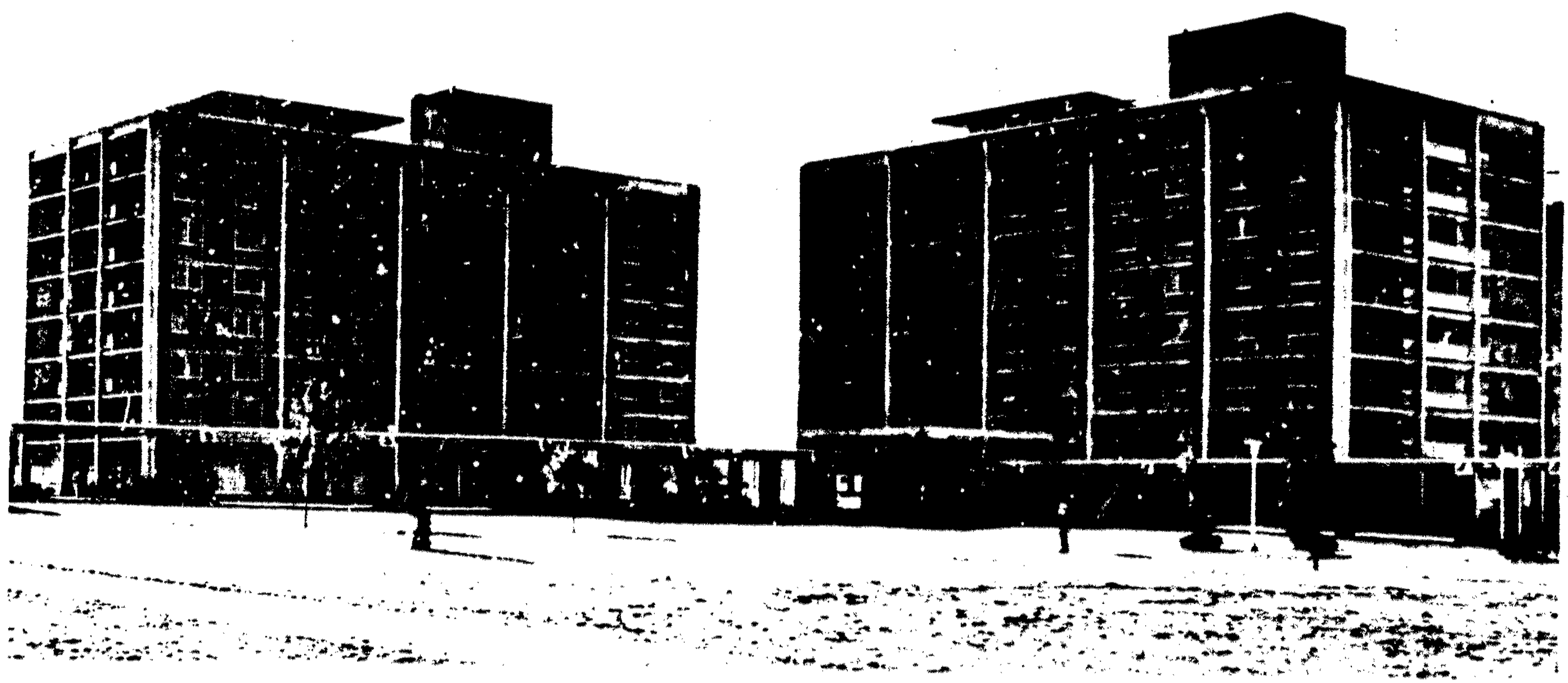


Figure 20. TEST BUILDINGS, EAST EXPOSURE

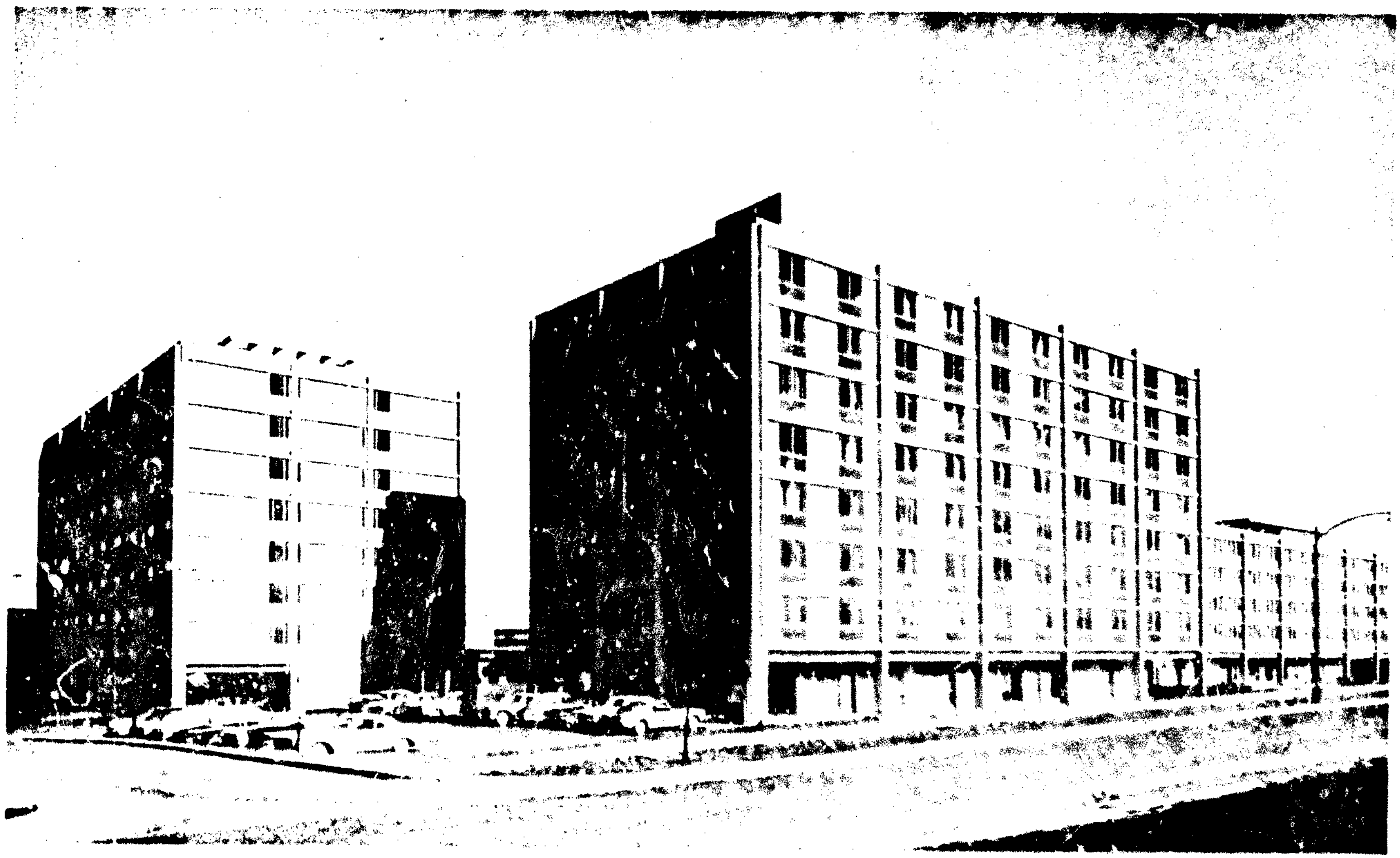


Figure 21. TEST BUILDINGS, WEST EXPOSURE

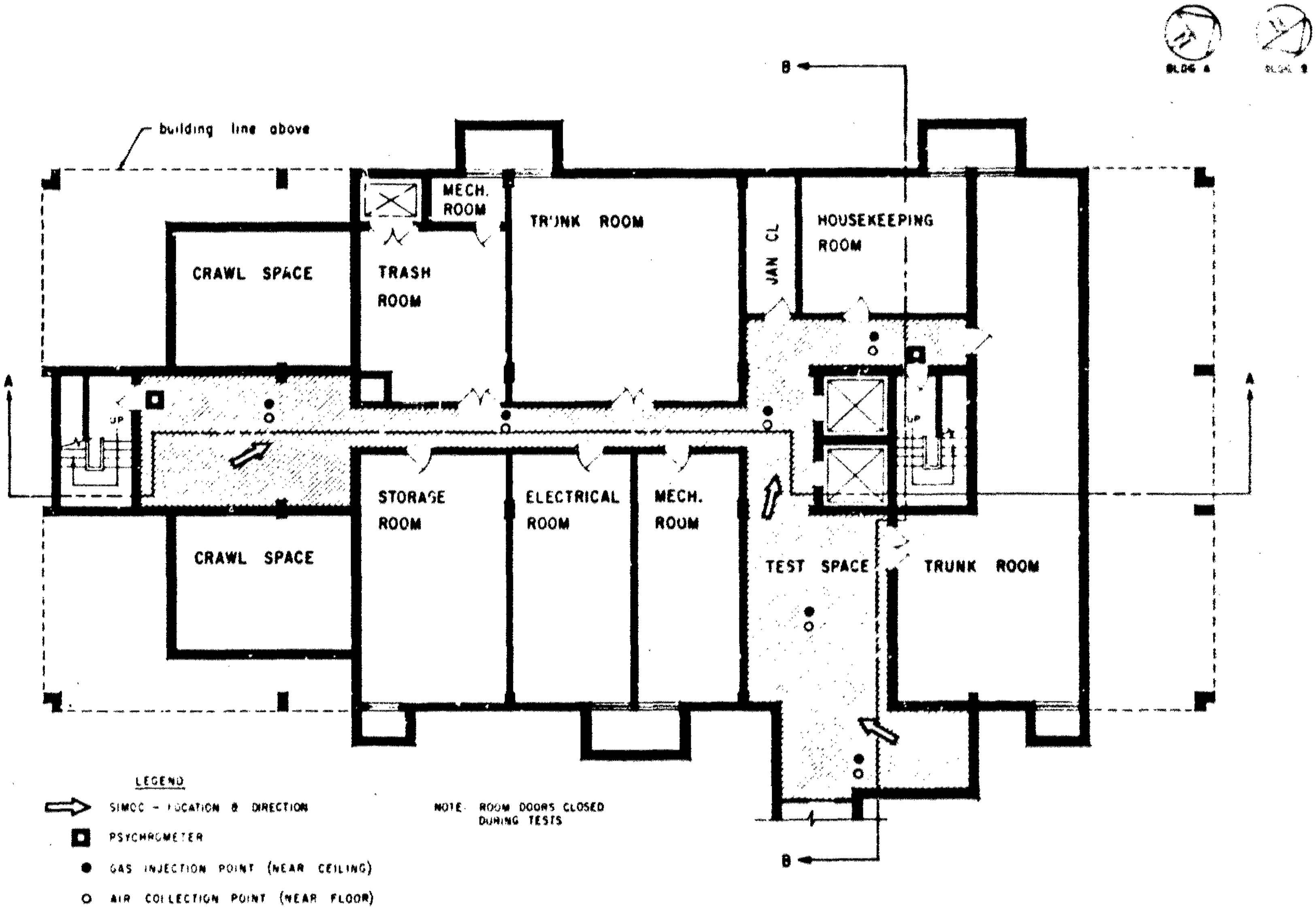
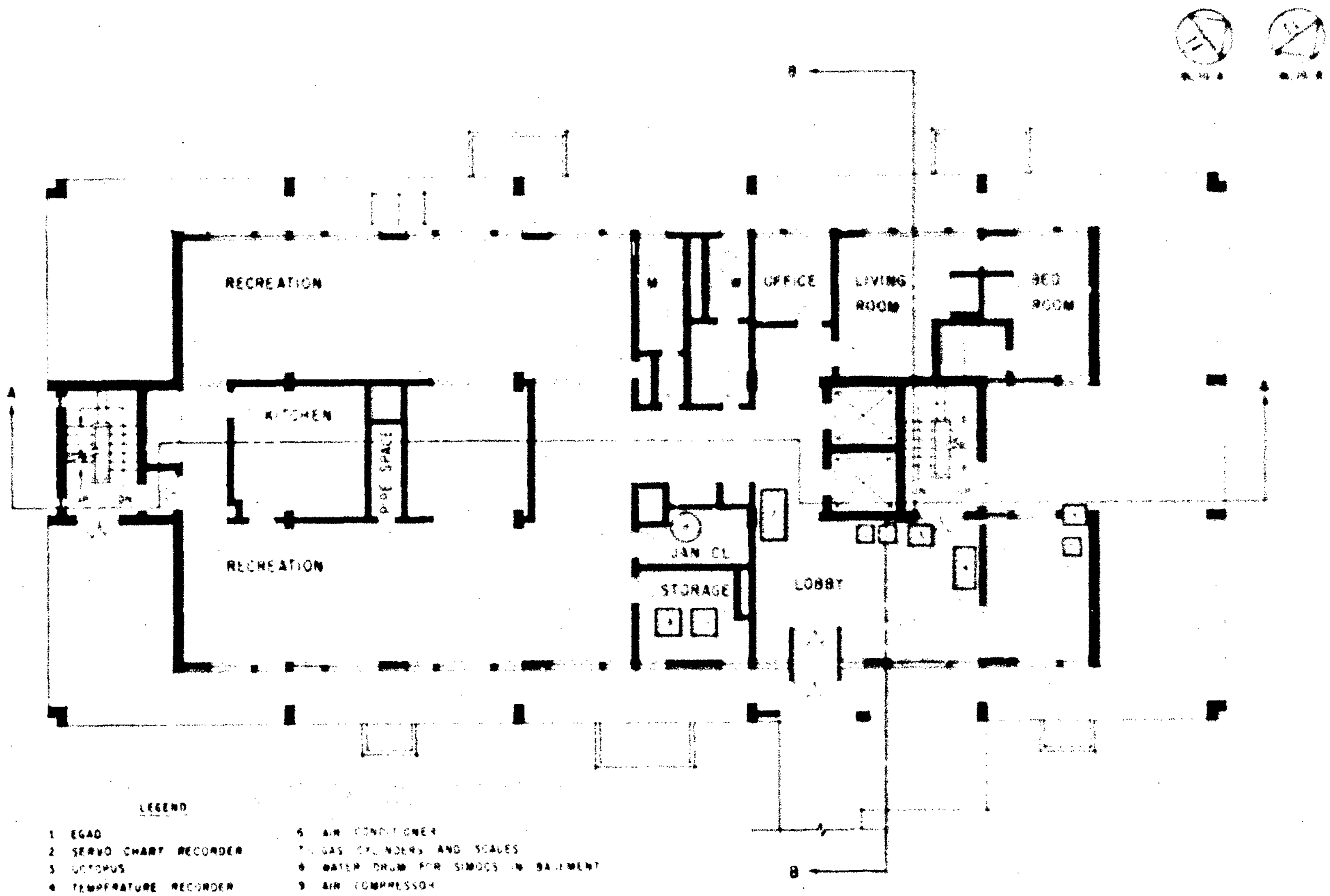


Figure 22. BASEMENT PLAN



LEGEND

1 EGAD
2 SERVO CHART RECORDER
3 OCTOPUS
4 TEMPERATURE RECORDER
5 VACUUM PUMP
6 AIR CONDITIONER
7 GAS CYLINDERS AND SCALES
8 WATER DRUM FOR SIMOCS IN BASEMENT
9 AIR COMPRESSOR
10 VACUUM CLEANER

NOTE EQUIPMENT IN BUILDING B ONLY
ROOM DOORS GENERALLY CLOSED DURING TESTS

Figure 23. FIRST FLOOR PLAN

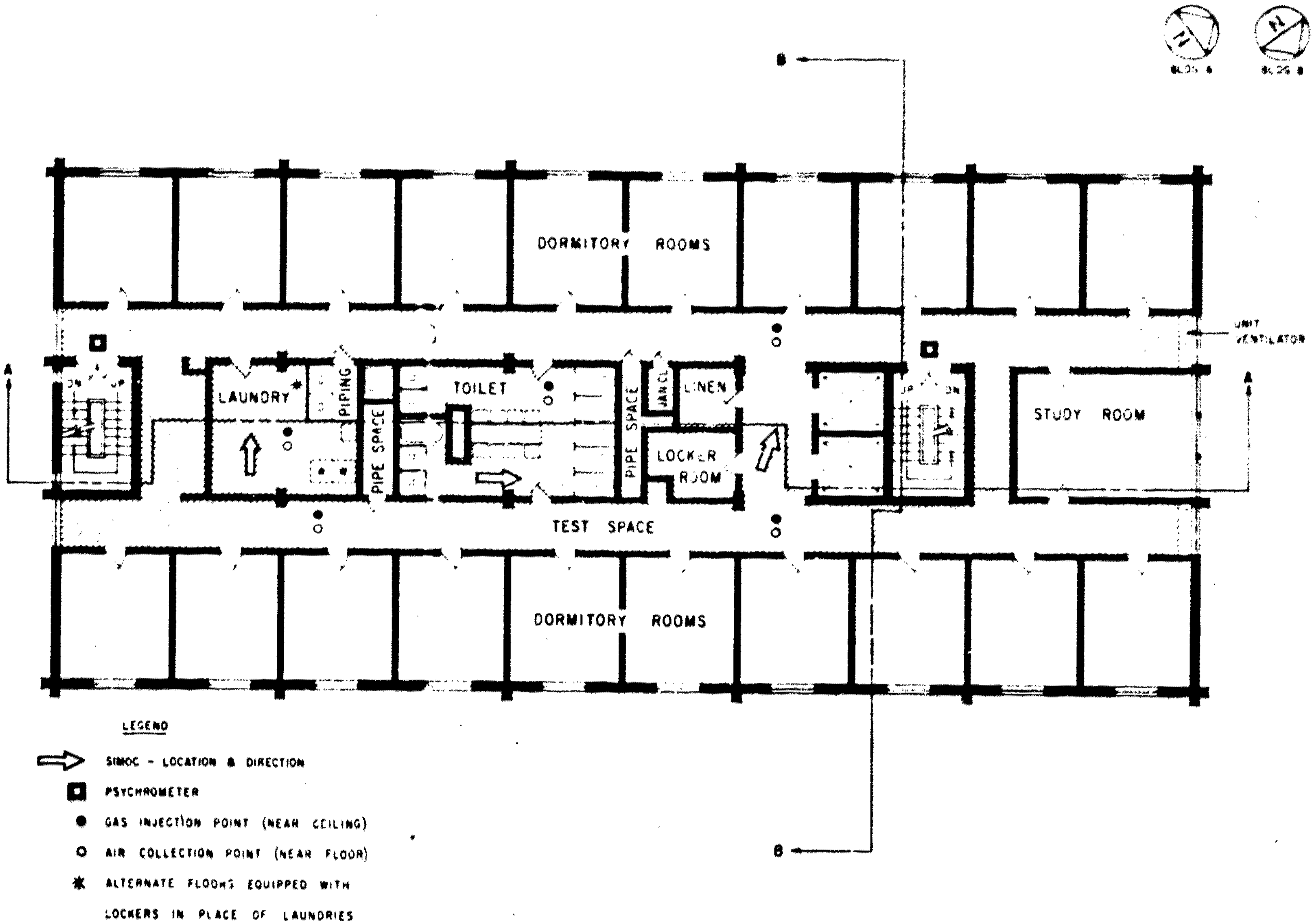


Figure 24. FIFTH FLOOR PLAN

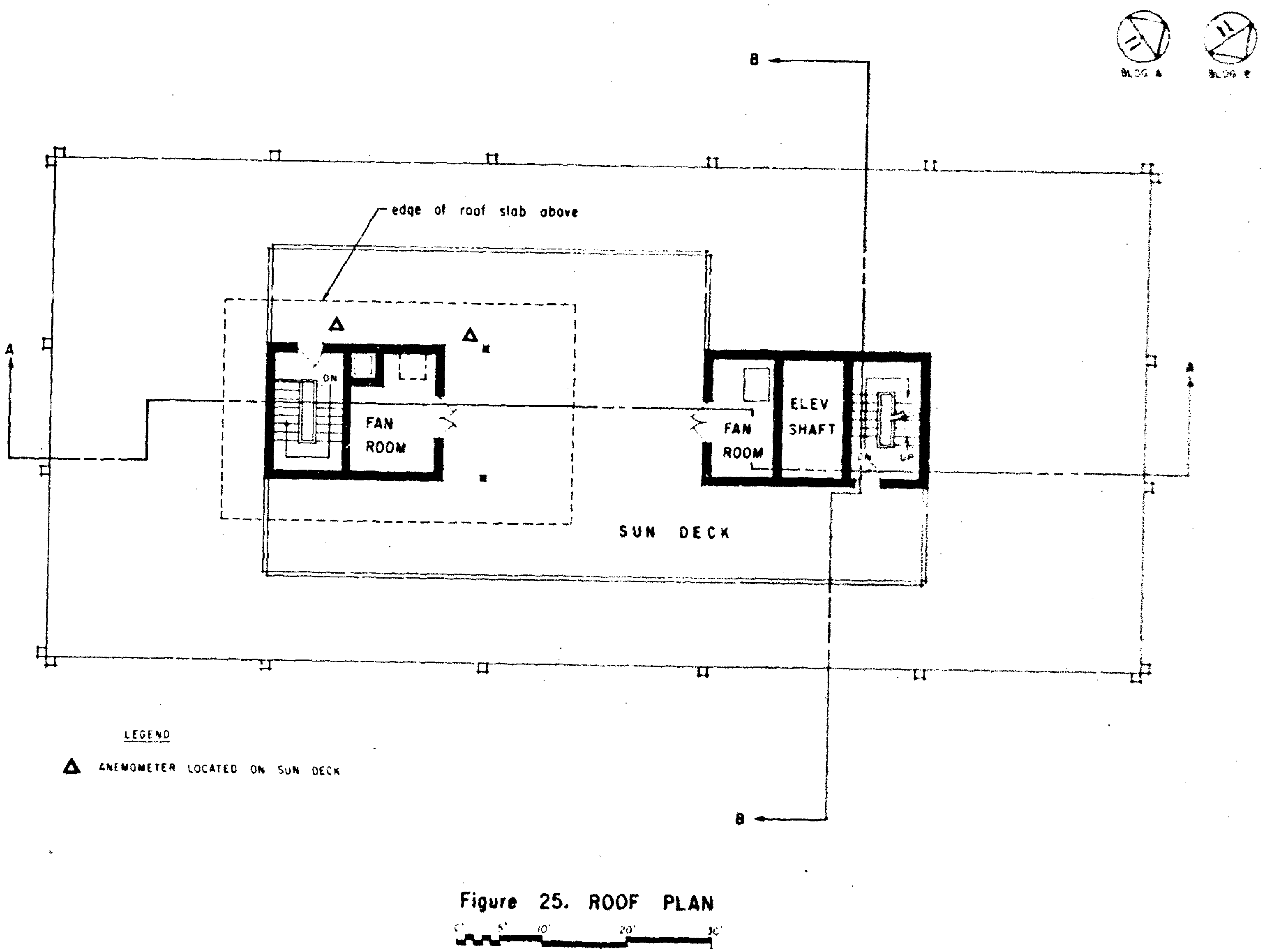


Figure 25. ROOF PLAN

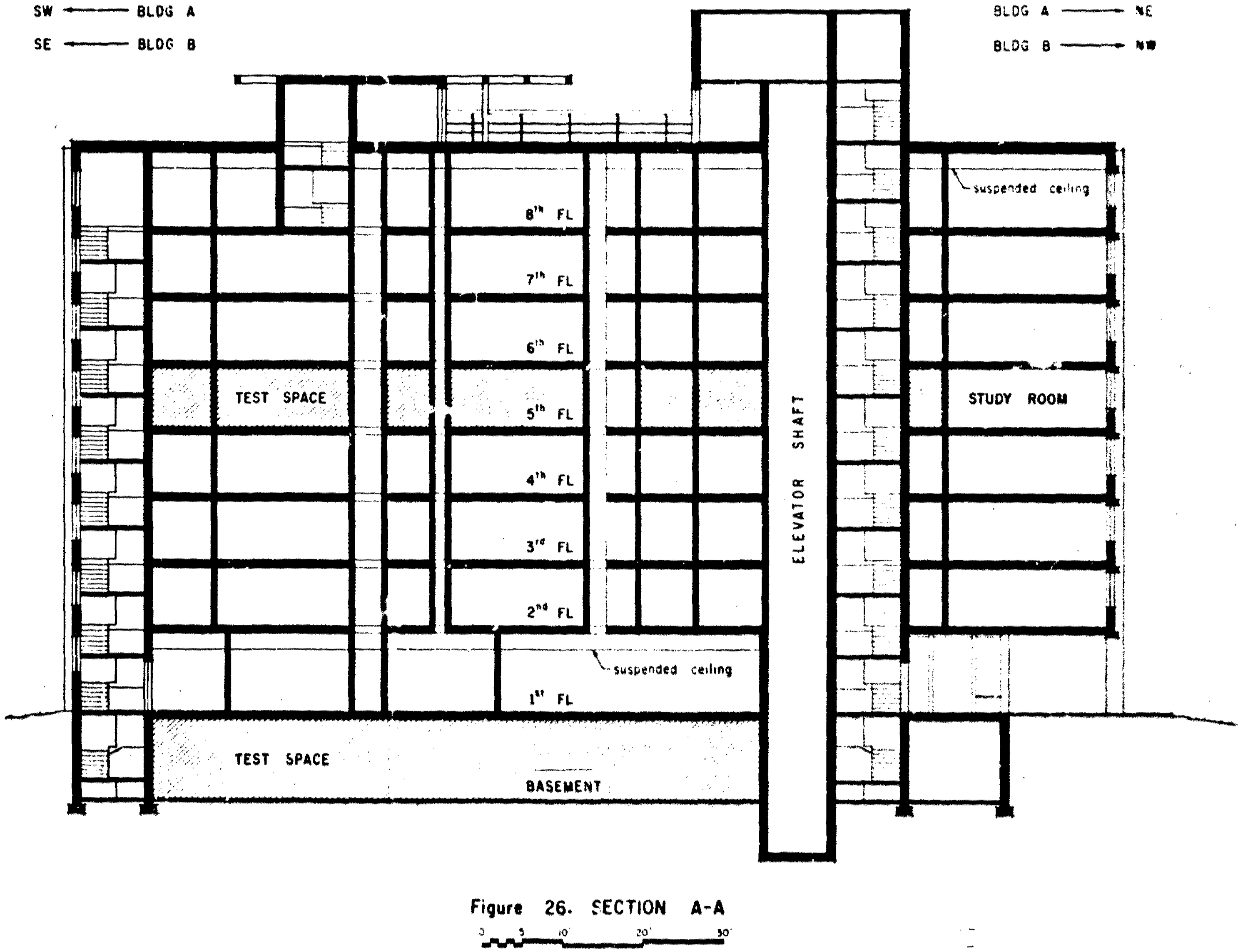


Figure 26. SECTION A-A

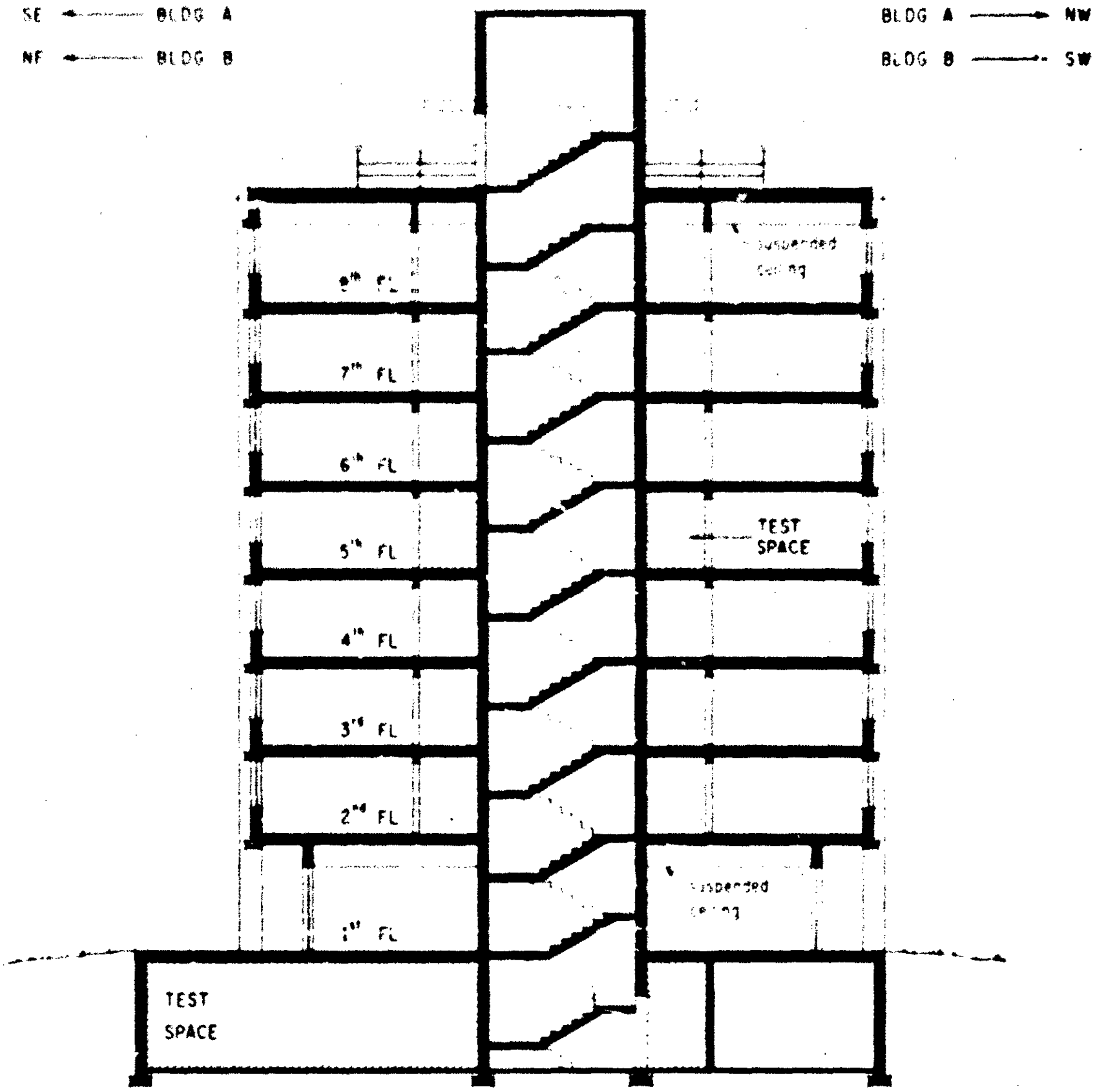


Figure 27. SECTION B-B

Dormitory rooms are located along the exterior side of the five foot wide corridors. In some tests, room doors were open while in other tests they were closed. Room doors have a 1" crack at the bottom but no ventilation grills. Elevator doors were kept closed, but were used by project personnel throughout the entire testing period, and therefore were not sealed.

4.5 SHELTER LOCATIONS AND SIZE

Floor area of the simulated shelter spaces in the basement is 1,419 square feet. Basement ceiling height is 10'-1" which provides a shelter space volume in the basement of 14,300 cubic feet. Figure 28 is a photograph of that space.

Figure 28.
PLASTIC PIPE IN BASEMENT

Figure 29.
FIFTH FLOOR SHELTER SPACES

Floor area of the simulated shelter spaces on the fifth floor is 2,505 square feet. Ceiling height, typical on all floors above the first, is 7'-6" which provides a fifth floor shelter space volume of 18,800 cubic feet. Figure 29 is a general view of the corridor portion of that space.

Total building volume including basement, but excluding penthouses is 431,460 cubic feet. Therefore, basement shelter space is approximately 3.31% of the total and fifth floor shelter space is approximately 4.35% of the total. The unit area in square feet per person and the unit volume in cubic feet per person, as stated in all test results, are based only on shaded areas whether the room doors are open or closed.

4.6 PREDICTED AIR CIRCULATION PATHS

One of the stair towers has an exterior wall containing two very narrow vertical windows at each floor level. The other tower is entirely interior, except for the first floor, and contains no windows. The exterior stair tower terminates at the eighth floor, while the interior tower continues on to the sun deck and elevator machine room as shown in Figure 26.

No effort was made to seal the windows, although they were kept closed and latched. All built-in mechanical ventilation fan units were turned off during the tests and grilles on the front of the unit ventilators were sealed as shown in Figure 30. It was anticipated that the heat generated by simulated occupants in either or both shelter spaces would create an air movement towards one of the stair towers

and cause an upward movement of air in that tower. The air would move across the building at one or more upper stories (depending upon location of open stair tower doors) and move down the other stair tower. Pressure differential at the base of these towers would be created by the infiltration of heated air, in addition to the heat generation by occupants. Actual circulation paths followed the predicted paths as shown in Figure 1.

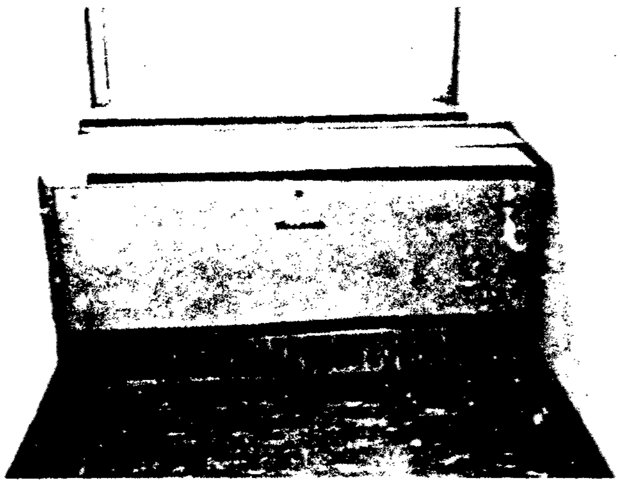


Figure 30. SEALED VENT GRILLES

4.7 THE CONTROL BUILDING

The dormitory building labeled A was intended to be used as a control in order to weight and evaluate the effects of external climatic conditions. As the test developed, it became apparent that no definite circulation paths within the building took place without a heater generator, such as occupants in designated spaces, but rather the entire volume of air in the building rose upward not unlike an expanding bubble. Results of tests reveal the nature of this air movement in control building A and a number of interesting points relative to the matter of natural infiltration.

4.8 SHELTER CAPABILITIES

Both buildings have been included in the National Shelter Survey and from the standpoints of radiation shielding shelter capacity meet all minimum shelter requirements.[14] The capability of sheltering large numbers of people for a two week period during hot humid weather, however, is dependent upon the amount of ventilation which can be provided. Various numbers of simulated occupants were placed in the basement shelter space and in the fifth floor shelter space. Tests were terminated when it became apparent that moisture accumulation on the building surfaces, furniture, and furnishings was reaching a potentially destructive level even though the effective temperature was below the commonly accepted limit of 85 F. In most cases, as seen by a study of tests results in a later section, the area per simulated occupant was greater than 10 square feet per person.

Time did not permit an investigation of the condition in which two or more of the upper floor shelters were occupied simultaneously. In order to assess the full shelter capability of one of these buildings, such a study is needed.

SECTION 5.0

PREPARATION OF TEST BUILDINGS

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SECTION 5.0 PREPARATION OF TEST BUILDINGS

5.1 TIGHTNESS CHECK

Since two buildings were to be used in the proposed tests it was advantageous to check the relative tightness of the buildings in relation to each other. The buildings were of the same configuration and built at the same time. However, differences in weatherstripping, window tightness, and other leakage factors could influence the infiltration rate. A large (10,000 cfm) fan was used, Figure 31, to create a pressure differential across the building by drawing the air out through the main entry door, Figure 32.

Figure 31.
PRESSURIZATION FAN

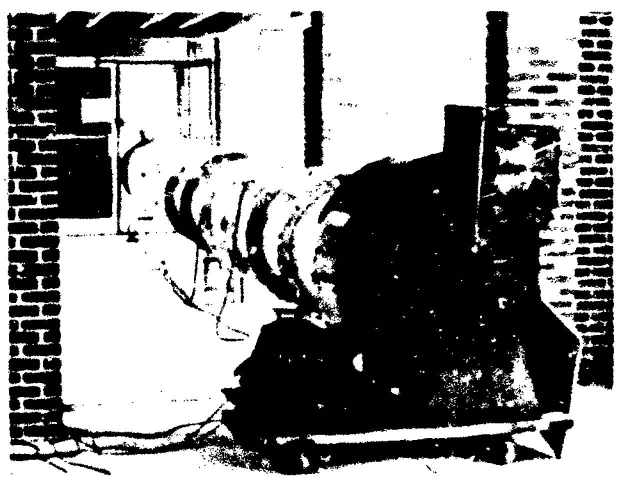
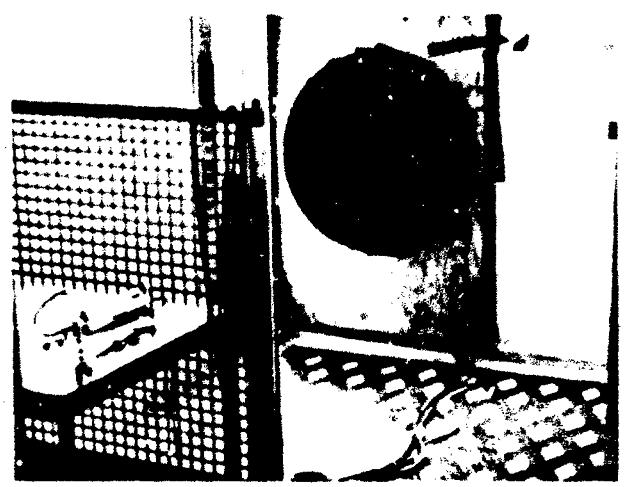


Figure 32.
ENTRANCE DOOR DUCT



The fan exhausted the air from the building which created a fairly uniform infiltration effect throughout the structure as shown in Figure 33.

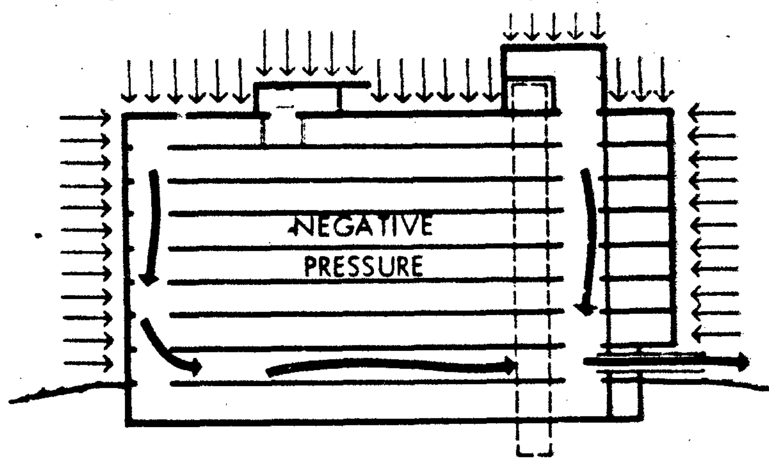


Figure 33. INFILTRATION CREATED BY REDUCED INTERNAL PRESSURE

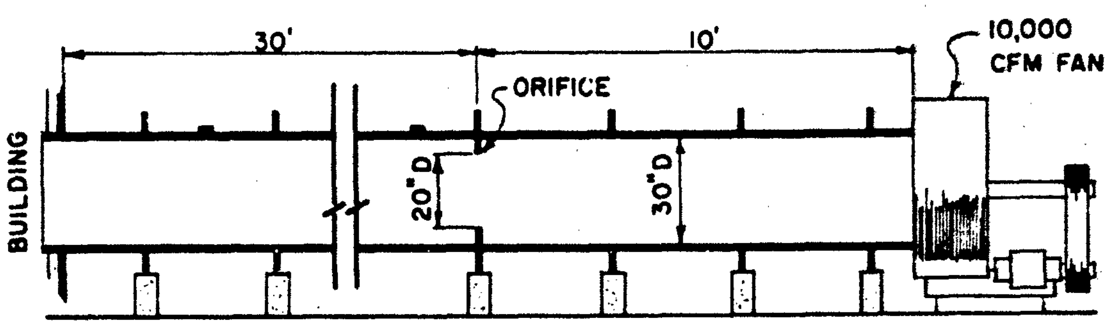


Figure 34. EXHAUST DUCT WITH ORIFICE

To measure the air flow, a 30-foot long 30-inch diameter duct was fabricated to attain uniform flow before the pressure differential was measured across the 20-inch diameter orifice which was inserted in the duct. See Figure 34. Since the building leakage rate would be influenced by infiltration through the ventilators, openings were sealed with 4 mil plastic film and canvas tape as shown in Figure 30. The

fire dampers within the three building exhaust ducts were tightly closed, thereby eliminating reverse leakage through their outlets. All windows in the building were tightly closed. Basement exhaust fans were shut down and their dampers checked for proper closing. The buildings remained in this closed condition for the duration of the tests.

5.2 USE OF EXHAUST FAN

A number of tests were run in building A at different volumes of air flow. A straight line relationship seemed to result between infiltration in cfm and leakage across the building. Figure 35 is a plot of infiltration rate vs. pressure differential. Only one pressurization test was made in building B. However, the resultant point lies within the limit of accuracy for the procedure in general, and on this basis it is concluded that the two buildings have approximately equal tightness.

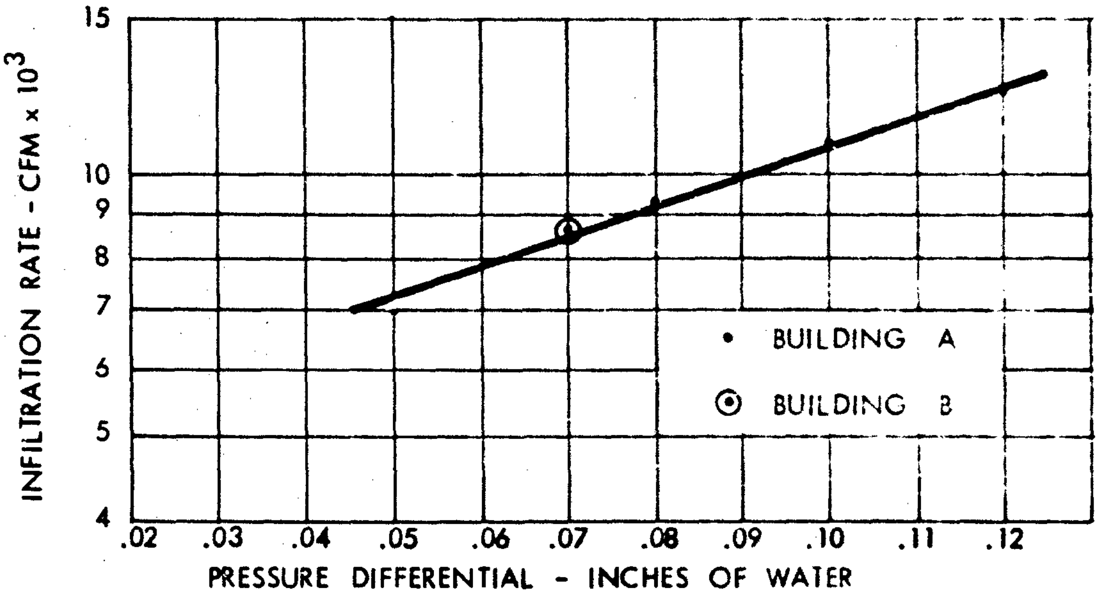


Figure 35. INFILTRATION RATE vs PRESSURE DIFFERENTIAL

5.3 INSTALLATION OF EQUIPMENT

Most of the test equipment was installed on the first floor of building B, shown in Figure 23, so that one person could monitor the tests and control the gas injection equipment. The temperature recording apparatus for building B, a 24 position copper-constantan thermocouple recorder shown in Figure 36, was also available to monitor all floor temperatures and outside temperatures. Since there were no shelters simulated in building A, its temperature recorder, the same type as in building B, was not in the test monitor space but was located on the first floor of A. In order to reduce the noise within the test equipment space, the air compressor and vacuum cleaner, shown in Figure 12, were located in a closed storage room with flexible tubing connections to the automatic multi-valve and the gas distribution equipment.

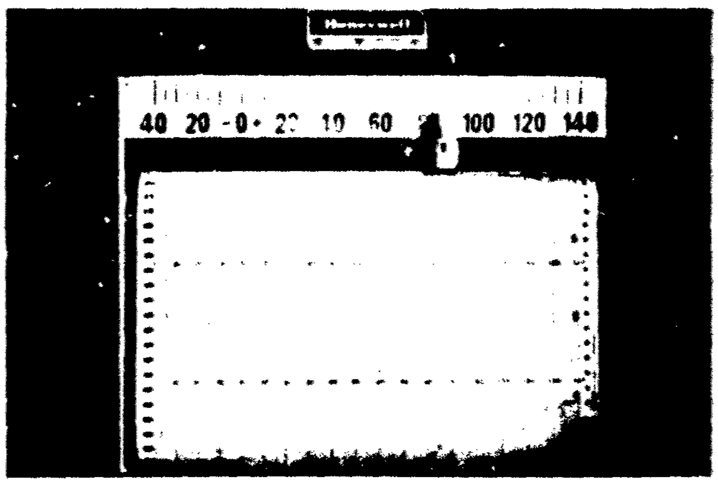


Figure 36. AUTOMATIC TEMPERATURE RECORDER

Two gas cylinders, Figure 15, were placed on platform balances to enable the operator to inject gas into two locations at the same time. This did not work out as expected because one of the two regulators available could not maintain an even flow for more than a few minutes at a time and, therefore, was not used for these

tests. This did not prove a great handicap because gas injection could be accomplished with one cylinder and regulator by switching injection tubes on the gas distribution manifold. Figure 37 shows a sketch of the gas distribution equipment.

Valve type aggregate Simoc equipment, made by the MRD division of The General American Transportation Corporation, was used to simulate occupancy in the shelter spaces.[15,16] Water for the Simoc was supplied by a constant level tank located one floor above the shelter space. The water was not weighed or metered because the Simoc equipment had been calibrated, and it was concluded that its built-in controls were adequate to regulate simulated occupancy levels. For basement Simoc equipment locations see Figure 22. Basement photographs, Figures 38 and 39 show the Simocs as installed.

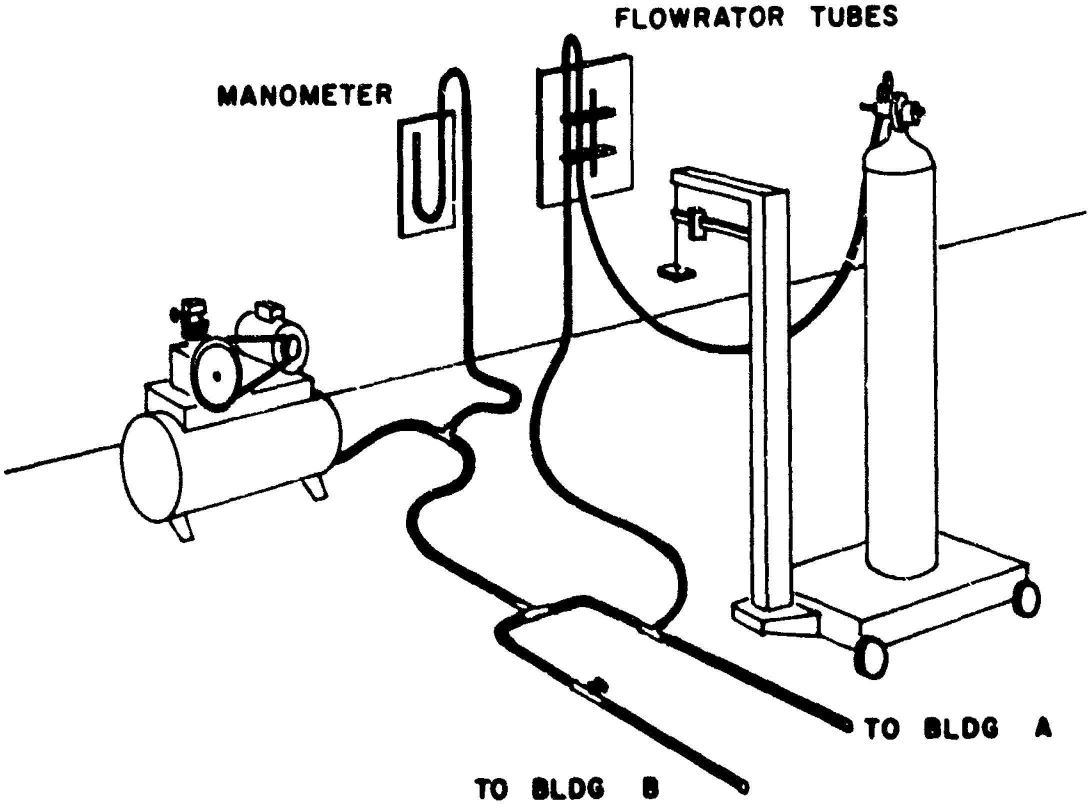


Figure 37. GAS DISTRIBUTION EQUIPMENT

Figure 38.
SIMOC IN BASEMENT
SPACE - LOOKING SE

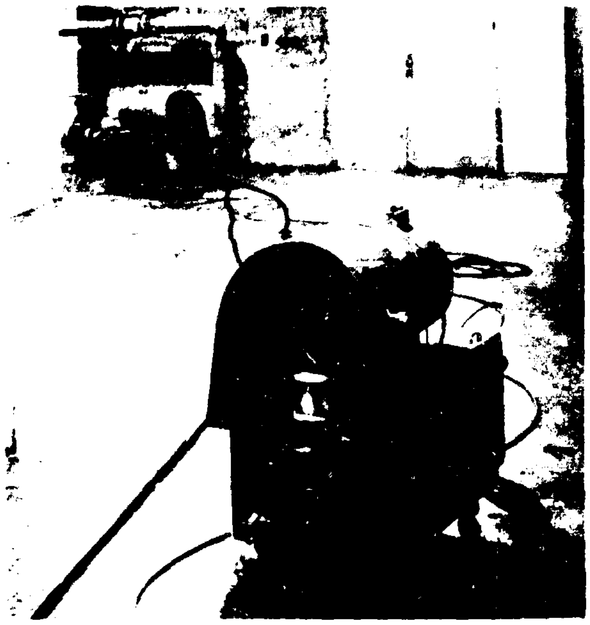


Figure 39.
SIMOCS IN BASEMENT
SPACE - LOOKING NE

Fifth floor Simoc locations were selected to load the larger spaces in the shelter and to reduce the effects of the Simoc directional characteristics which might influence natural air flow patterns within the shelter. The fifth floor plan, Figure 24, shows Simoc locations. Figures 40, 41 and 42 show the actual Simocs as installed.

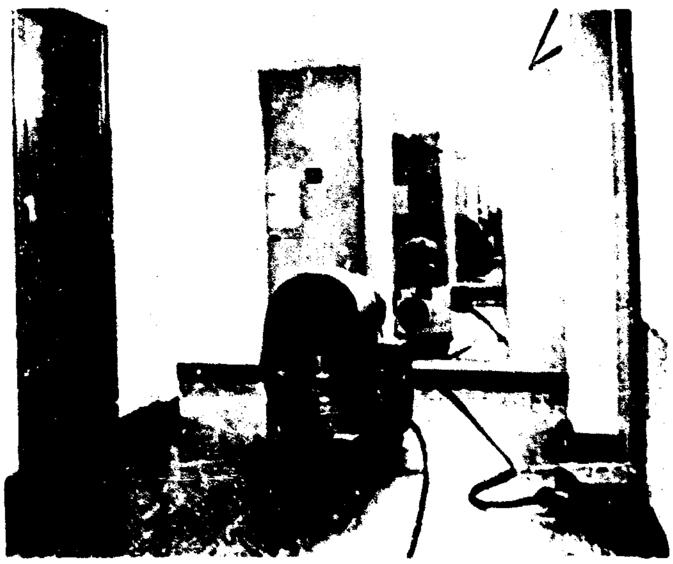


Figure 40. SIMOC IN FIFTH FLOOR CORRIDOR

Figure 41. SIMOC IN FIFTH FLOOR BATHROOM

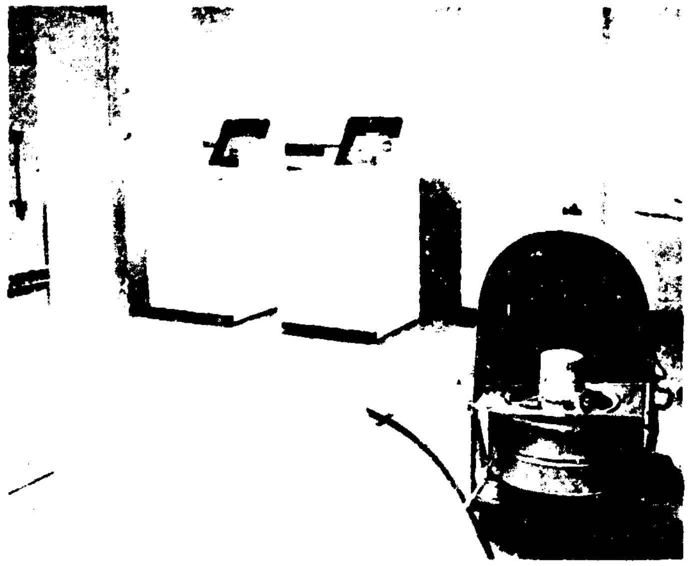


Figure 42. SIMOC IN FIFTH FLOOR LAUNDRY

Aspirating psychrometers of the type shown in Figure 43 were located at the inlet and outlet of each shelter space, as well as on the exterior of building B to record outdoor dry bulb and wet bulb conditions. These devices were connected to the automatic temperature recorder shown in Figure 36.

Figure 43. ASPIRATING PSYCHROMETER

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SECTION 6.0

BUILDING A TESTS

SECTION 6.0 BUILDING A TESTS

6.1 GENERAL OBJECTIVES FOR BUILDING A

The general objectives in using a control building were to study air movement in the building without occupants, and to separate the effects of outdoor climatic conditions from the effects of indoor heat generation, as produced by simulated occupants. As test results indicate, it was not possible to meet these objectives completely. Nevertheless, the data obtained from Building A reveals some interesting facts concerning the relationship between outdoor conditions and internal conditions.

6.2 TEMPERATURE VARIATIONS INSIDE BUILDING A

In general, there seems to be an increase in temperature, floor by floor, from bottom to top of the building. An exception was found on the top floor where the temperature dropped slightly, probably due to the closeness of the roof construction and to the duct space above the suspended ceiling. An expanding bubble or balloon effect rather than a circulatory effect was noted in Building A as compared with Building B. Figure 44 is a graph showing a floor by floor relationship of temperature vs. time for a 24 hour period. The fifth floor data have been omitted for clarity, but generally the temperature on that floor was somewhere between the temperatures on the fourth and sixth floor.

6.3 EFFECT OF OUTDOOR TEMPERATURE ON INDOOR TEMPERATURE

Except for the first floor where there was much glass area and operable doors there was no marked effect between the outdoor temperature and indoor temperature.

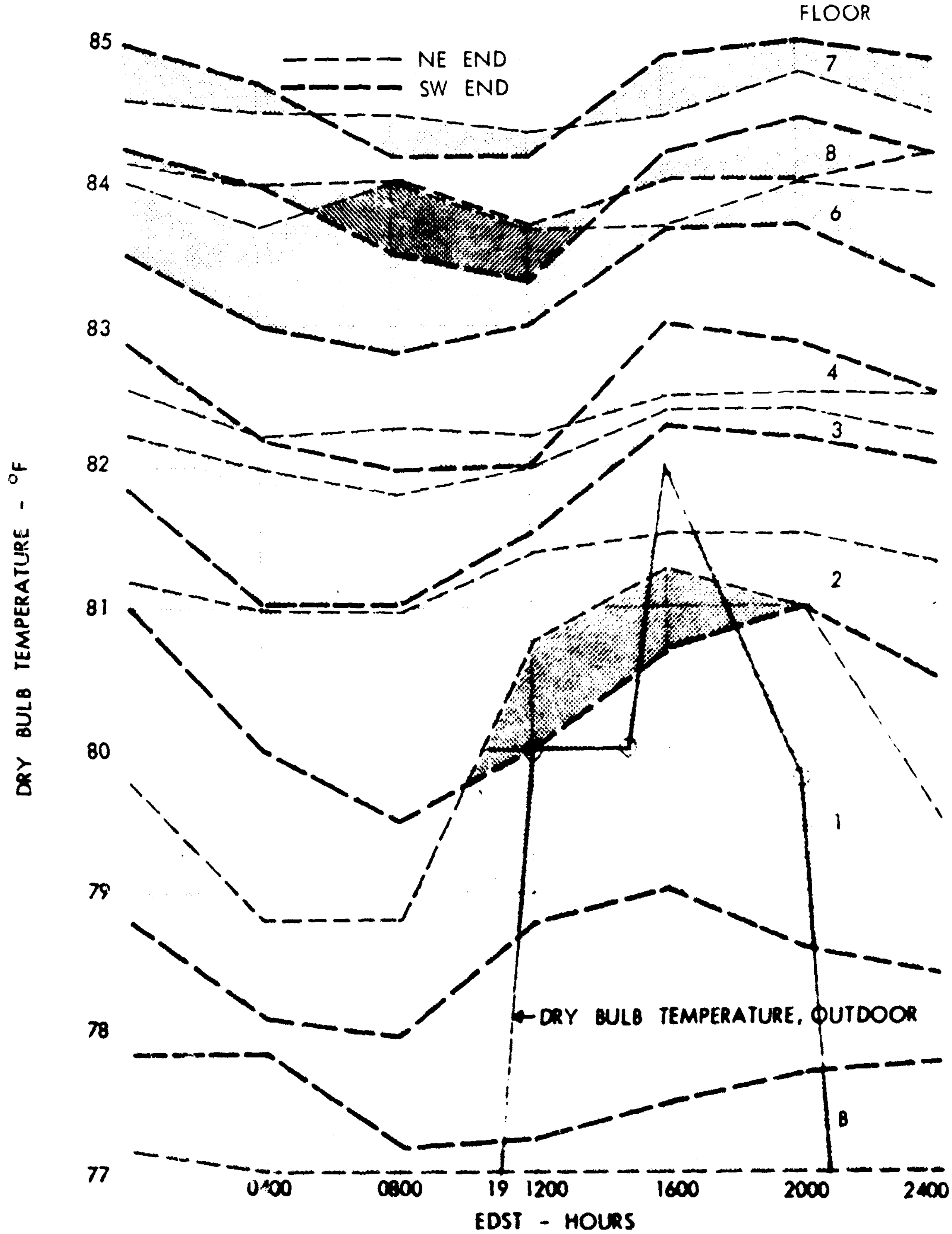


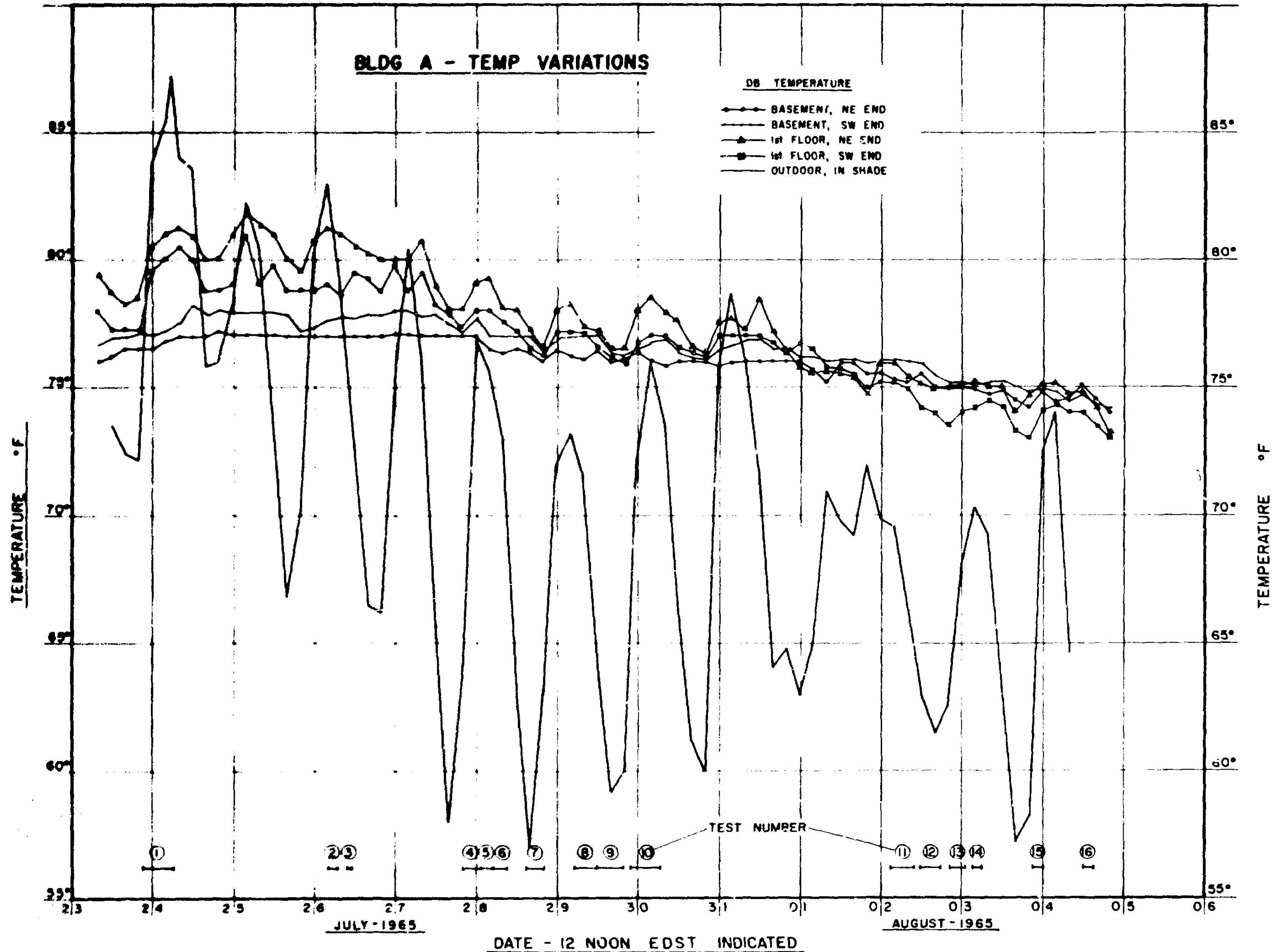
Figure 44. TEMPERATURE vs TIME IN BUILDING A ON 7/26/65

Generally, this lack of correlation could be attributed to the inertia of the masonry building construction. Figure 45 is a plot of temperature variations at both ends of the basement and first floor as related to outdoor dry bulb temperature over the period of testing in Building A.

6.4 INDIVIDUAL TESTS IN BUILDING A

Figure 46 is a summary of air change rates in Building A as determined by the rate of decay method. Observations were made both with the dormitory room doors closed and with dormitory room doors open. In each case, the tracer gas was injected into the corridor and core room spaces. The air samples were also taken from the corridor and core room spaces. Decay rates with the room doors closed, Figure 47, were generally faster than the rates with the doors open, Figure 48.

There are two contributing factors for this relative difference in decay rates. Factor No. 1, the room doors were undercut to provide an opening at least 1 inch wide along the bottom of the door. A tight fitting door would be expected to be a considerable impediment to the flow of air from the room to the corridor and the infiltration should be considerably reduced. With a relatively large opening available, any air passing through the building envelope into the rooms had very little difficulty passing from the rooms to the corridor, whether the doors were open or not. Similarly, any air passing from the corridor to the rooms and subsequently from the rooms to the weather had very little difficulty passing from the corridor to the room whether the doors were open or not. Therefore, a closed door which would be expected to offer resistance to air flow and reduce the infiltration rate had no perceptible effect on the infiltration or exfiltration rates through the building envelope.



BLDG A - TEMP VARIATIONS
DB TEMPERATURE
BASEMENT, NE END
BASEMENT, SW END
1st FLOOR, NE END
1st FLOOR, SW END
OUTDOOR, IN SHADE
TEMPERATURE °F
85°
80°
75°
70°
65°
60°
55°
TEST NUMBER
23
24
25
26
27
28
29
30
31
01
02
03
04
05
06
JULY - 1965
AUGUST - 1965
DATE - 12 NOON EDST INDICATED

Figure 45

TEST #		1A	2A	3A	4A	5A	6A	7A	8A	9A	10A	11A	12A	13A	14A	15A	16A
DATE		7/24	7/26	7/26	7/28	7/28	7/28	7/29	7/29	7/30	7/30	8/2	8/2-8/3	8/3	8/3	8/3	8/4
EDST		0930-1830	1600-2100	2100-2400	0830-1330	1400-1730	1730-2100	0300-0800	1700-2400	0000-0800	1000-1900	1430-2200	2330-0600	0830-1330	1530-1800	1900-2300	0830-1200
WIND DIRECTION / MPH		W E 9-11.5	0-13	0	9-16	11-16	10-14	0-3.5	0-7	4-6	2-5	8-17	9-13	13-16	5	2-9	0-1
OUTDOOR DB, °F		80-8[illegible]	74-83	76-69	77-67	76-75	75-69	59-55	73-67	67-57	66-77	63-71	61	58-62	70.5	61-71	62-60
DORM RM DOORS		closed	closed	closed	closed	closed	closed	open	open	open	open	open	open	open	closed	closed	closed
		FRESH AIR CHANGES PER HOUR															
FLOOR	8	0.37	0.27	0.33	0.29	0.52	*	0.31	*	0.17	*	0.55	0.35	0.22	0.16	0.50	*
FLOOR	7	0.34	0.22	0.33	0.37	0.63	0.16	0.34	0.13	0.22	0.06	0.46	0.35	0.22	0.37	0.42	0.41
FLOOR	6	0.34	0.60	0.56	0.68	0.96	0.26	0.41	0.17	0.27	0.08	0.37	0.15	0.24	0.42	0.53	0.46
FLOOR	5	0.43	0.49	1.17	0.78	1.18	0.36	0.49	0.26	0.41	0.18	0.39	0.31	0.39	0.83	0.71	0.55
FLOOR	4	0.46	0.61	1.16	1.05	1.19	0.51	0.57	0.29	0.56	0.31	0.49	0.33	0.40	0.97	1.15	0.77
FLOOR	3	0.46	0.69	1.39	1.48	1.57	1.13	1.09	0.64	0.44	0.34	0.56	0.51	0.48	1.30	1.42	*
FLOOR	2	0.39	0.70	1.66	1.73	1.67	0.97	*	*	*	*	*	*	*	*	*	*
FLOOR	1	0.42	0.56	1.30	1.10	1.24	1.61	1.40	*	*	0.28	0.52	1.08	1.46	*	1.87	*
FLOOR	B	0.35	0.55	0.85	1.30	1.23	1.85	*	*	*	0.38	0.88	1.02	1.31	*	1.12	*
WEIGHTED AVERAGE		0.40	0.52	0.97	0.94	1.12	0.72	0.63	0.30	0.35	0.21	0.49	0.44	0.48	0.68	0.91	*

* Insufficient data available

Figure 46. SUMMARY OF AIR CHANGES IN BUILDING A

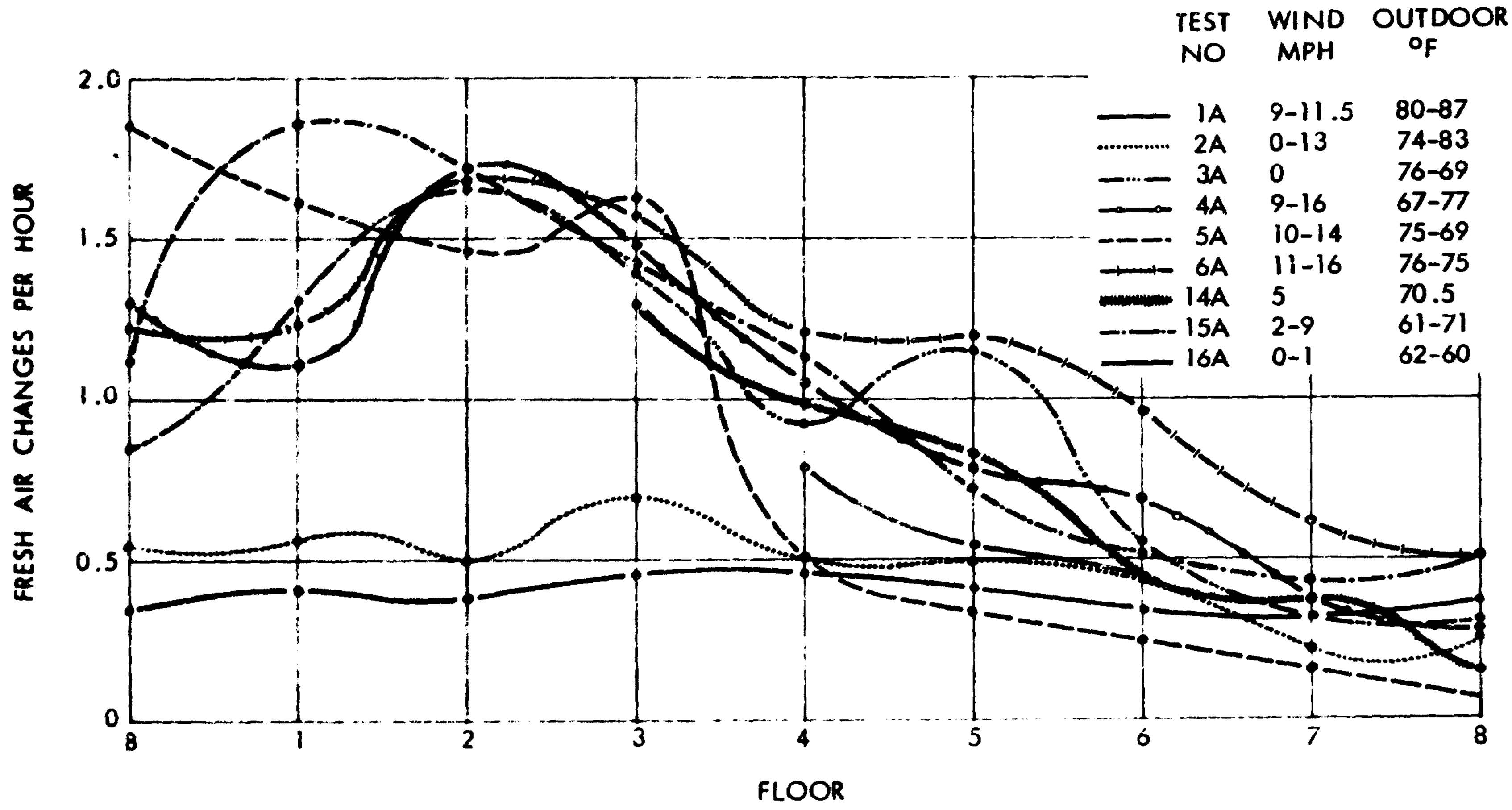


Figure 47. AIR CHANGE RATE - ROOM DOORS CLOSED

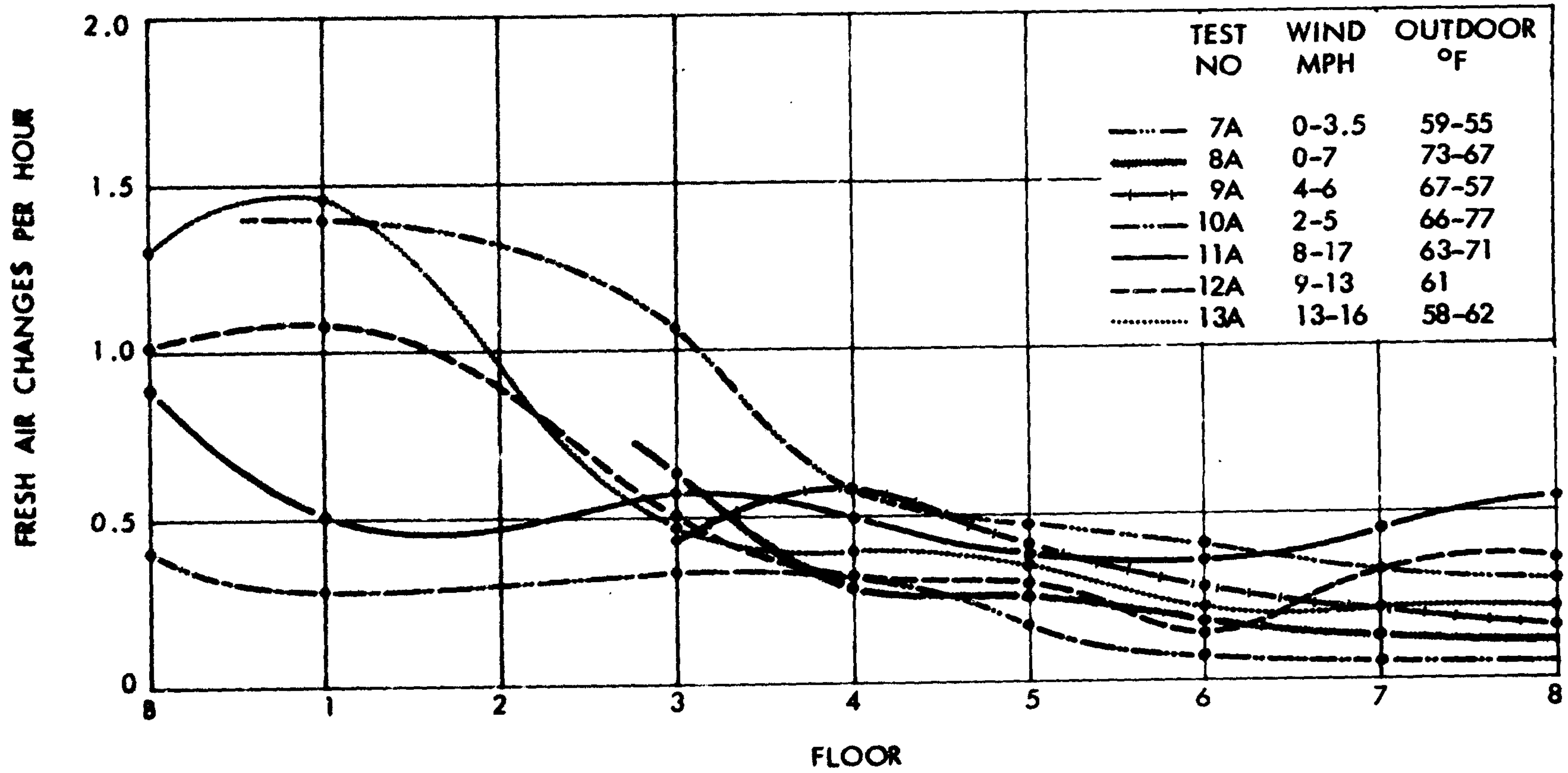


Figure 48. AIR CHANGE RATE - ROOM DOORS OPEN

Factor No. 1 alone does not increase the decay rate in the corridor with the doors closed but in effect provides the same infiltration rate, which, because of factor No. 2 allows the decay rate to be larger when the doors are closed.

NOTE: If closing the room doors reduced the infiltration through the building envelope substantially, the decay rate in the corridor with the doors closed could be less than the decay rate with the doors open.

This second factor, which makes the corridor decay rate greater with the doors closed, is the reduced volume available for mixing. The tracer gas injected into the corridor mixed with the corridor air only. Any infiltrating air flowing under the room doors <u>from</u> the rooms to the corridor prevented the tracer gas in the corridor from convecting into the rooms. The volume of the room was isolated from the volume of the corridor and therefore, was not a part of the volume in which decay was taking place. Exfiltrating air flowing from the corridor to the rooms had the same effect as air exfiltrating through the building envelope. The volume of these rooms was isolated also from the volume of the corridor and was not a part of the volume in which decay was taking place. Under these conditions, the decay rate and air change rate are related to the volume of the corridor and core spaces only.

When the room doors were open, the tracer gas from the corridor could mix with the room air by convection through the door opening. Under these conditions, the decay rate and air change rate are related to the total volume of the corridor and core rooms <u>plus</u> the dormitory rooms.

Figure 49 contains two curves, one an average of the higher rates of air change observed with the room doors closed as plotted in Figure 47, and the other an average

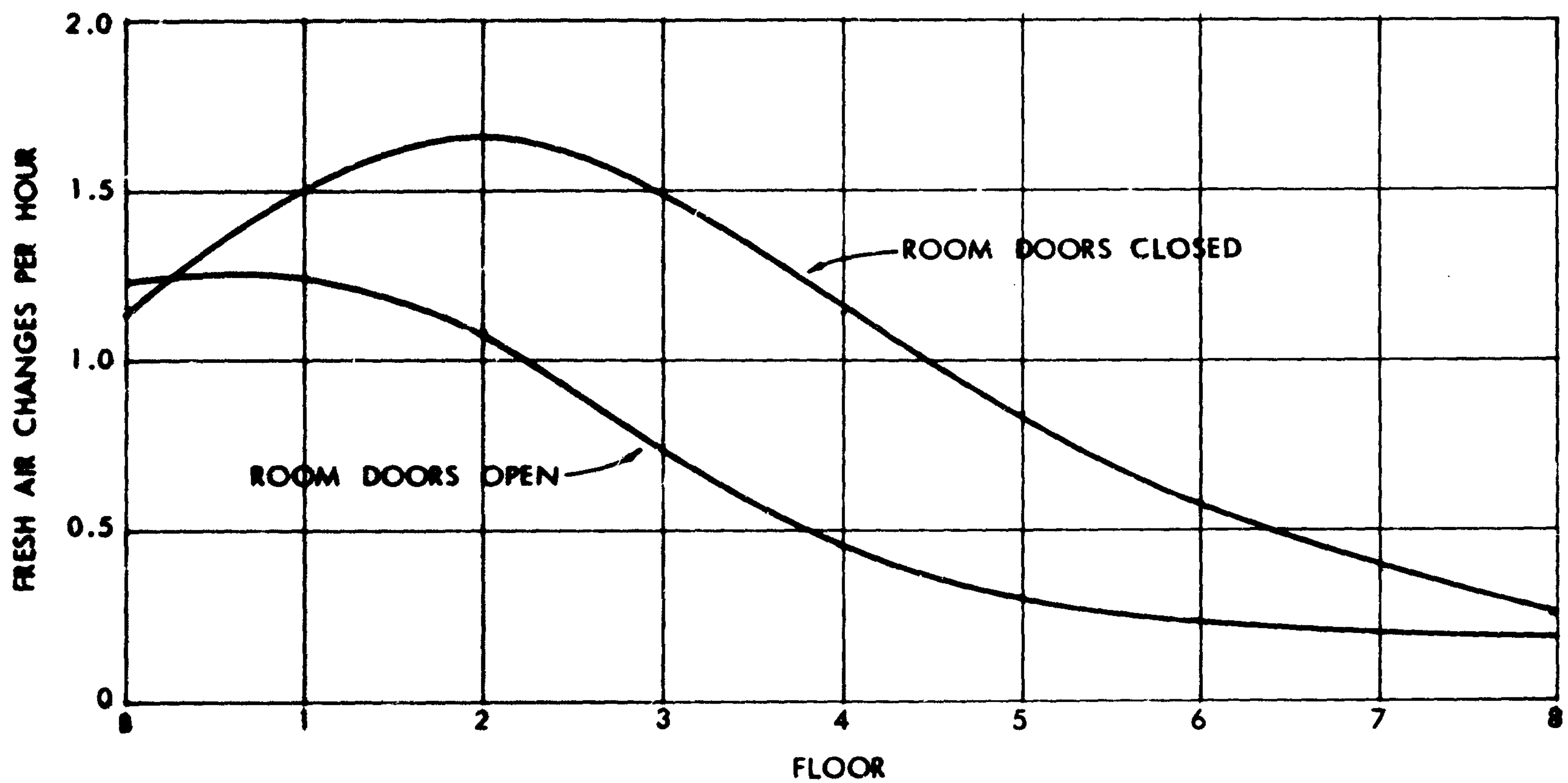


Figure 49. COMPARISON - ROOM DOORS CLOSED VS. ROOM DOORS OPEN

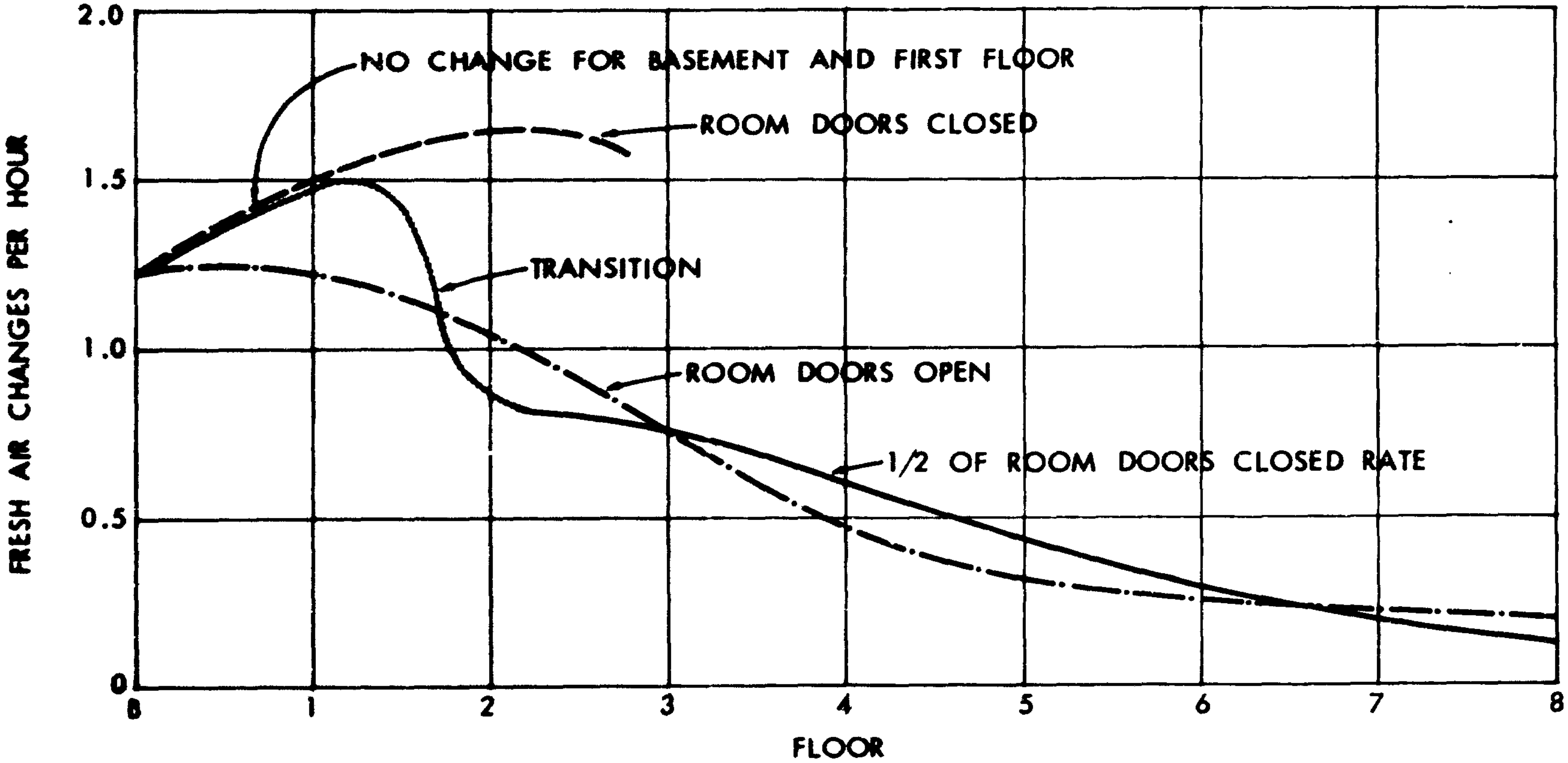


Figure 50. CORRELATION BETWEEN - ROOM DOORS CLOSED AND ROOM DOORS OPEN

of the lower rates of air change observed with the room doors open as plotted in Figure 48.

These curves are combined in Figure 50. Also shown in this figure is a solid line curve which is one-half the rate of air change observed with the doors closed. The one-half rate represents an arbitrary figure to take cognizance of the fact that some mixing of air between corridor and rooms takes place even with the room doors closed. The agreement between the two curves is very good for all floors above the second floor. The equipment was removed from the second floor for other purposes before the open door observations were made, and consequently there is no good comparison for the second floor. There were no dormitory rooms on the first floor or in the basement. Agreement between the curves for the basement is very good. On the first floor the rate observed when the dormitory room doors of the floors above were open is lower than the rate observed when the room doors were closed. The reason for this is obscure but may be due to observational problems since the difference of 0.25 air changes is relatively small for observation of this type.

There are two tests for each door condition where the ventilation rates of the lower floors are much below the average of the other observations. During Test 1A the outdoor air temperature was high and equal to or above the air temperature observed with the building. This would indicate that under these conditions the density of the indoor air was equal to or higher than the density of the outdoor air. Therefore, there was a tendency for the indoor air either to be stagnent or to flow outward at the lower floors. These conditions were also present for part of the building during Test 2A. During all other observations with the room doors closed the outdoor air

was cooler and more dense than indoor and the tendency was for outdoor air to flow into the lower floors and out of the upper floors. During Tests 1A and 2A the air change rates on the lower floors were only slightly higher than the floors above. In all other observations the air change rates for the basement and lower floors were significantly higher than the rates for the floors above.

A similar relationship existed for the results with the room doors open. Test 10A, and to a lesser extent 11A, exhibits a low rate of air change on the lower floors. The reason is obscure, since the outdoor air temperature was below the indoor air temperature in both cases. In one case, 10A, the outdoor air temperature was rising, and in the other case, 11A, the outdoor air temperature was falling. During 10A the wind was relatively calm which during 11A the wind was relatively strong. No unique condition appears to account for the fact that air change rates of 10A and 11A differed from all other tests.

SECTION 7.0

BUILDING B TESTS

SECTION 7.0 BUILDING B TESTS

7.1 GENERAL OBJECTIVES FOR BUILDING B

Within the time limitations imposed by availability of the buildings, an effort was made to explore the natural ventilation rate in Building B with respect to both basement shelter space and fifth floor shelter space, singly and concurrently occupied. Portable ventilation equipment arrived late and was used in only three sets of tests, numbers 3, 14 and 15. Simulated occupancy of shelter spaces varied but was kept below the commonly accepted maximum density of 1 person per 10 square feet because of excessive condensation which threatened to damage the building and its contents.

7.2 SUMMARY OF AIR CHANGES IN SHELTER SPACES

Figure 51 is a complete summary of air changes in shelter spaces together with pertinent information concerning weather conditions, door positions and shelter occupancy. Detailed information on individual tests is given later. In all cases, area and volume per person are based on areas and volumes of cores as shown in Figures 22 and 24.

7.3 TEST COMPARISONS

Summary information, together with building air flow sketches, is presented four to a page in order to permit the reader to compare the results of successive tests. An effort can be made to correlate external with internal conditions, and shelter occupancy with flow rate, but such correlations are not immediately evident.

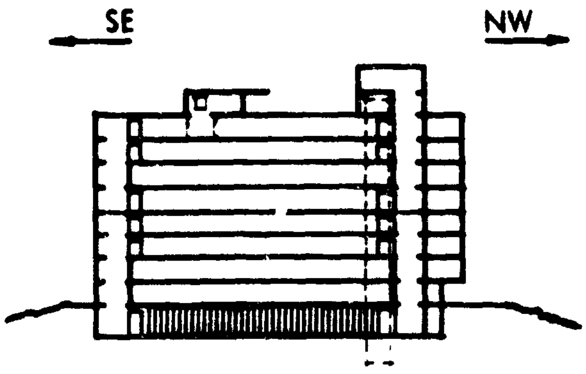
TEST #		1B	2B	3B	4B	5B	6B	7B	8B	9B	10B	11B*	12B*	13B*	14B*	15B	16B*	17B*	18B*	19B*
DATE		7/24	7/26	7/26	7/27	7/27	7/28	7/28	7/28	7/29	7/29	7/29-7/30	7/30	8/2	8/2	8/2	8/4	8/4	8/4	8/4
EDST		1040-1830	0930-1430	1440-1600	1740-1850	1900-2000	0000-0300	2100-2230	2240-2400	0040-0140	0200-0300	1600-1100	1100-2400	1120-1400	1550-2200	2200-2300	0900-1600	1610-1835	1835-2200	2200-2300
WIND DIRECTION / MPH		9-11.5	4-15	11-14	0-11	8-17	0-4	2-6	0-2	0-3.5	3.5	6-9	6-9	14-16	14-16	14-16	2-9	4-7	0-5	0-1
OUTDOOR DB, °F		80-97	83-72	82-84	80-79	79-76	65-60	69-67	68-63	63-61	61-58	57-74	77-68	68-70	71-68	63	61-76	74	65	64
DORM ROOM DOORS		closed	closed	open	closed	closed	closed	open	closed	closed	open	closed	closed	closed	closed	closed	closed	closed	closed	closed
STAIRTOWER 5th FL LEVEL		closed	closed	closed	closed	closed	closed	closed	open	open	open	open	open	open	open	open	open	open	open	open
BASEMENT	OCCUPANTS	0	0	0	0	0	75	0	140	140	0	140	140	0	0	0	140	140	140	140
BASEMENT	HIGHEST ET, °F	74.0	73.0	74.0			77.0		79.0	77.0		80.0	80.0				78.0	79.0	75.0	73.5
BASEMENT	AIR CHANGES/HR	0.99	0.85	0.63**			1.78		2.37	3.75		3.72	3.22				2.07	7.70	45.0	10.7
BASEMENT	CFM/PERSON						5.65		4.00	6.10		6.30	3.86				3.50	13.20	77.0	18.2
5th FLOOR	OCCUPANTS	0	0	0	75	75	75	75	0	0	75	75	100	100	100	100	100	100	100	100
5th FLOOR	HIGHEST ET, °F				80.0	80.0	78.0	79.5			77.0	78.0	79.5	77.0	76.0 / 81.0	81.0	76.0	78.5	76.0	76.0
5th FLOOR	AIR CHANGES/HR				1.08	1.18		1.55			0.92			1.00	1.05 / 1.73**	1.58**				
5th FLOOR	CFM/PERSON				4.50	4.90		6.50			3.88			8.00	8.40 / 13.80**	4.95**				

Data not taken

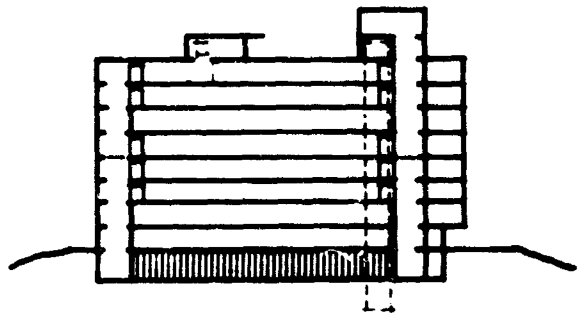
* Sustained rate method used (5th floor volume includes dormitory rooms)
** Pedal fan on

Figure 51. SUMMARY OF AIR CHANGES IN SHELTER SPACES OF BUILDING B

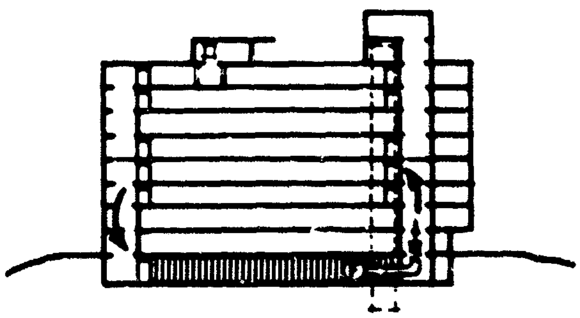
Tests 1 through 4 are presented in Figure 52, 5 through 8 in Figure 53, 9 through 12 in Figure 54, 13 through 16 in Figure 55 and 17 through 19 in Figure 56. Stair tower doors are shown either open or closed to reflect the actual position during the test.



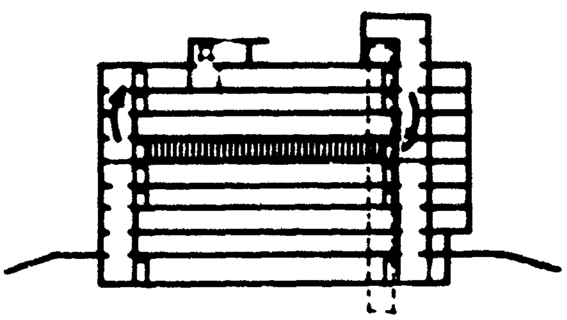
TEST NO. 1B
Stairtowers sealed between 4th and 5th floor
Shelter space unoccupied
0.99 air changes per hour in shelter space
No well defined air circulation
▯ – open door
| – closed door



TEST NO. 2B
Stairtowers sealed between 4th and 5th floor
Shelter space unoccupied
Shelter stairtower doors closed but not sealed
0.85 air changes per hour in shelter space

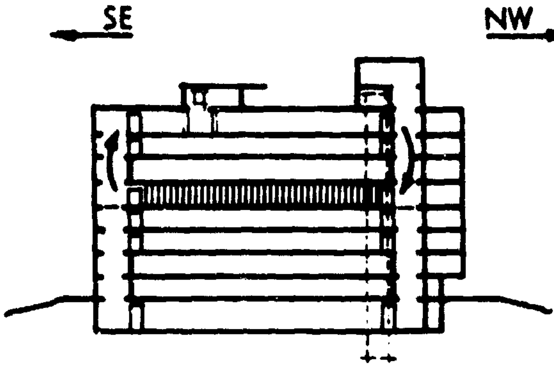


TEST NO. 3B
Stairtowers sealed between 4th and 5th floor
Shelter space unoccupied
Pedal fan used in shelter
0.63 air changes per hour in shelter space

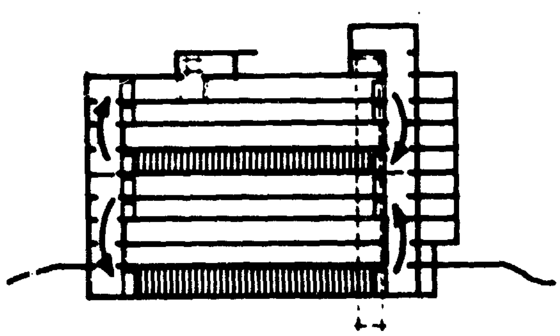


TEST NO. 4B
Stairtowers sealed between 4th and 5th floor
75 simulated persons in shelter
Dormitory room doors closed
1.08 air changes per hour in shelter space
4.50 cfm per person

Figure 52. SUMMARY OF TESTS 1B - 4B

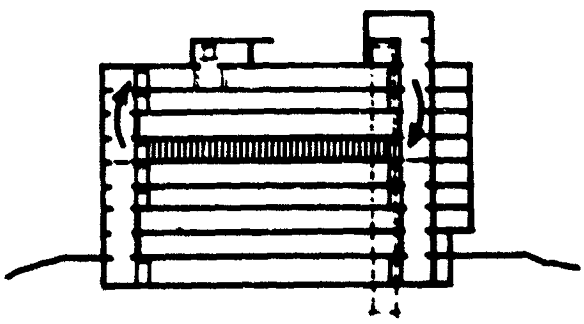


TEST NO. 5B
Stairtowers sealed between 4th and 5th floor
75 simulated persons in shelter
Dormitory room doors closed
1.18 air changes per hour in shelter space
4.90 cfm per person
▯ — open door
| — closed door

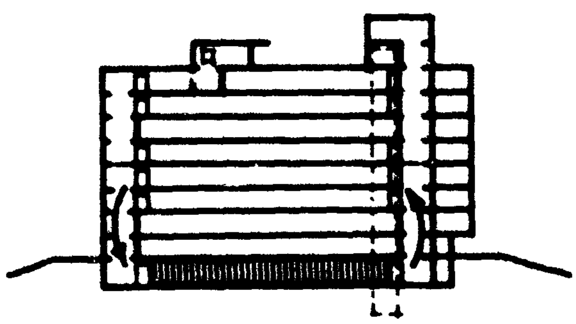


TEST NO. 6B
Stairtowers sealed between 4th and 5th floor
5th floor dormitory room doors open .

	Bsm't	5th floor
Shelter occupancy	75	75
Air changes per hour	1.78	not measured
Cfm per person	5.65	not measured

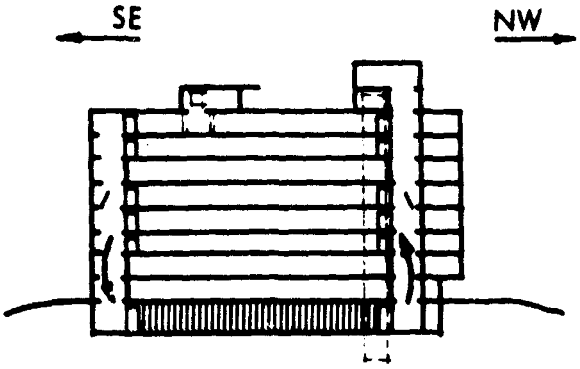


TEST NO. 7B
Stairtowers sealed between 4th and 5th floor
75 simulated persons in shelter
Dormitory room doors open
1.55 air changes per hour in shelter space
6.50 cfm per person

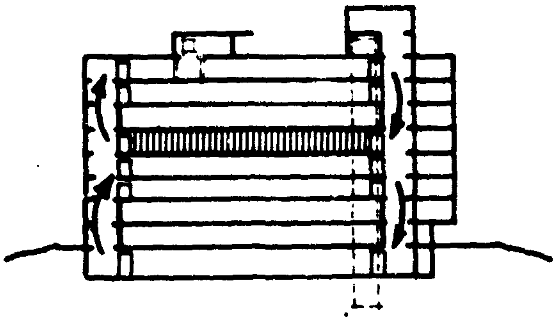


TEST NO. 8B
Stairtowers sealed between 4th and 5th floor
140 simulated persons in shelter
2.37 air changes per hour in shelter space
4.00 cfm per person

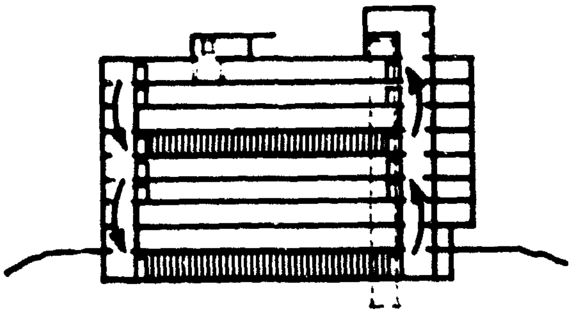
Figure 53. SUMMARY OF TESTS 5B - 8B



TEST NO. 9B
Stairtower seals between 4th and 5th floor removed during this test
140 simulated persons in shelter
3.57 air change per hour in shelter space
6.10 cfm per person
□ — open door
| —• closed door

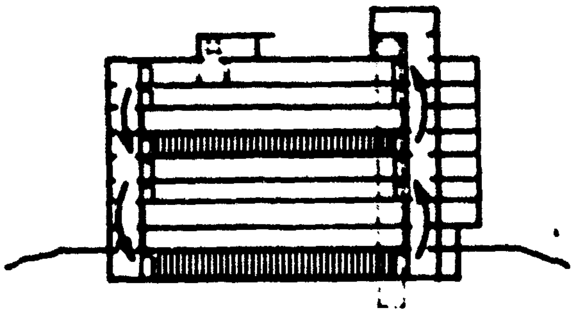


TEST NO. 10B
75 simulated persons in shelter
Dormitory room doors open
0.92 air changes per hour in shelter space
3.90 cfm per person



TEST NO. 11B
Dormitory room doors open
Sustained rate injection method used

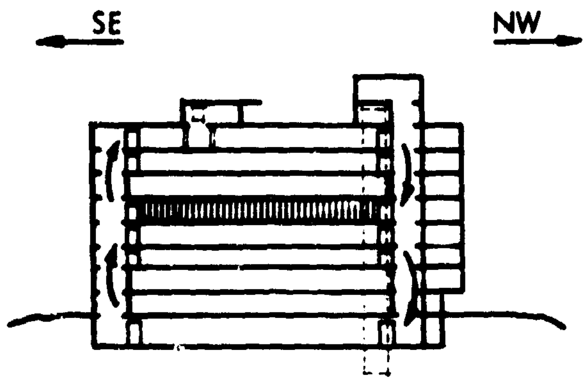
	Bsm't	5th floor
Shelter occupancy	140.	100.
Air changes per hour	3.72	not measured
Cfm per person	6.30	not measured



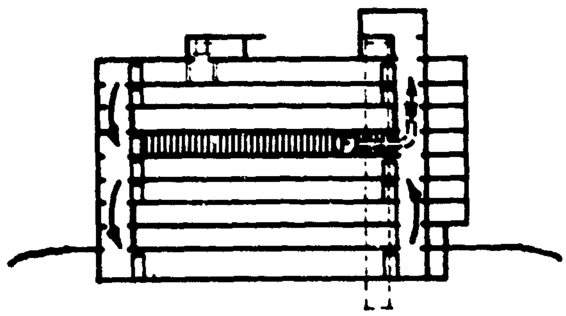
TEST NO. 12B
Dormitory room doors initially open but closed during the progress of the test
Sustained rate injection method used

	Bsm't	5th floor
Shelter occupancy	140.	100.
Air changes per hour	3.22	not measured
Cfm per person	3.86	not measured

Figure 54. SUMMARY OF TESTS 9B - 12B

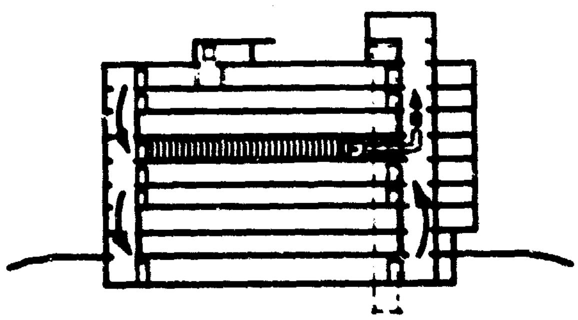


TEST NO. 13B
100 simulated persons in shelter
5th floor dormitory room doors closed
Sustained rate injection method used
1.00 air changes per hour in shelter space
7.25 cfm per person
▯ — open door
| — closed door

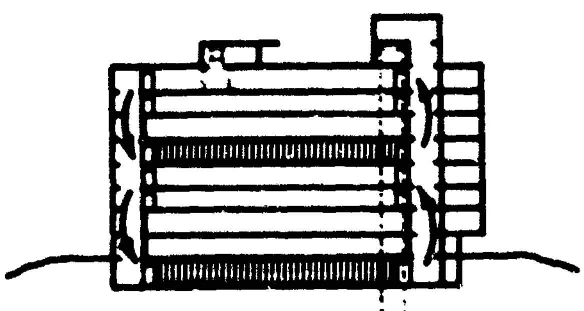


TEST NO. 14B
100 simulated persons in shelter
5th floor dormitory room doors closed
Sustained rate injection method used

Pedal fan	OFF	ON
Air changes per hour	1.05	1.73
Cfm per person	8.40	13.80



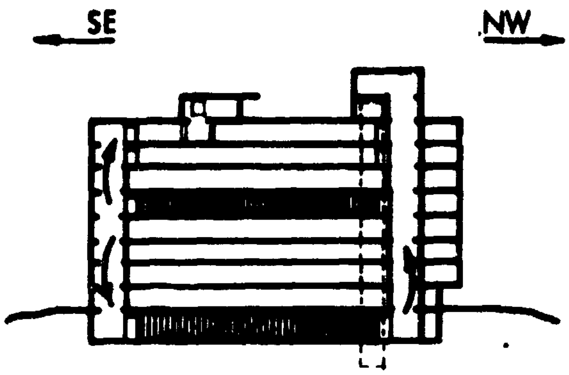
TEST NO. 15B
100 simulated persons in shelter
5th floor dormitory room doors closed
Pedal fan used in shelter
1.58 air changes per hour in shelter space
4.95 cfm per person



TEST NO. 16B
Sustained rate injection method used
5th floor dormitory room doors open

	Bsm't	5th floor
Shelter occupancy	140.	100.
Air changes per hour	3.50	not measured
Cfm per person	2.07	not measured

Figure 55. SUMMARY OF TESTS 13B - 16B



TEST NO. 17B

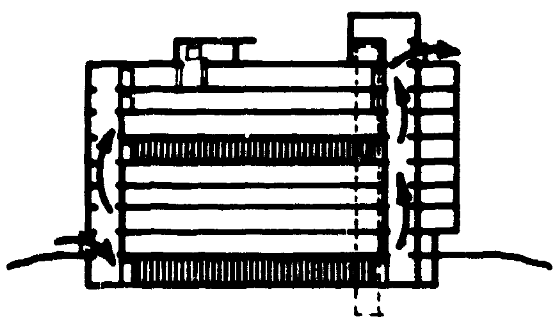
5th floor dormitory room doors open

Sustained rate injection method used

	Bsm't	5th floor
Shelter occupancy	140.	100.
Air changes per hour	7.70	not measured
Cfm per person	13.2	not measured

□ — open door

| — closed door



TEST NO. 18B

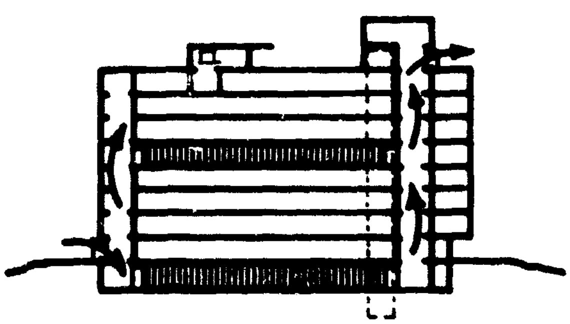
Exterior doors to stairtowers opened as shown

Stairtower doors at 7th and 8th floor levels are open

5th floor dormitory room doors open

Sustained rate injection method used

	Bsm't	5th floor
Shelter occupancy	140.	100.
Air changes per hour	45.0	not measured
Cfm per person	77.0	not measured



TEST NO. 19B

Exterior doors to stairtower opened as shown

Stairtower doors at 7th and 8th floor levels are open

5th floor dormitory doors open

	Bsm't	5th floor
Shelter occupancy	140.	100.
Air changes per hour	10.7	not measured
Cfm per person	18.2	not measured

Figure 56. SUMMARY OF TESTS 17B - 19B

7.4 INDIVIDUAL TEST RESULTS 1 THROUGH 13

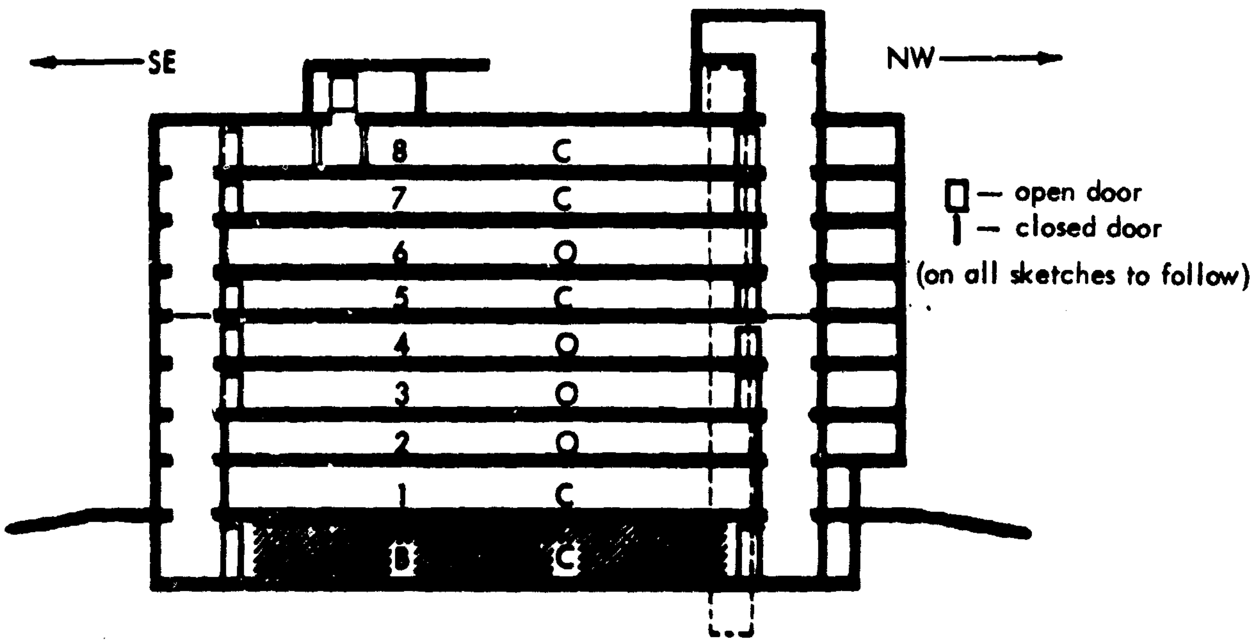
A detailed presentation of each test conducted in Building B follows, one to a page. The information includes external and internal conditions, shelter occupancy, rate of air flow and special conditions relating to the tests. Figures 57 through 59 pertain to tests 1 through 3 respectively.

BUILDING B
TEST NO. 1

SHELTER OCCUPANCY
0 persons

LENGTH OF TEST: 8 hours
7/24/65 (1040 hrs) to
7/24/65 (1830 hrs)

RATE OF AIR FLOW
0.99 air changes/hr



C: room doors closed
O: room doors open
▒: simulated shelter

Shelter inlet
& outlet,
each 18 sq ft

OUTDOOR CONDITIONS	
Air dbt:	80 - 87F
Air wbt:	76 - 79F
Relative humidity:	65 - 72%
Wind direction:	N15W - W
Wind speed:	9.2 - 11.5 mph

SHELTER CONDITIONS		
Air dbt:	inlet	77.0F
	outlet	77.0F
Air wbt:	inlet	71.0F
	outlet	71.0F
Effective temp:	inlet	74.0F
	outlet	74.0F

SPECIAL CONDITIONS AND COMMENTS
Shelter unoccupied
Stairtowers sealed between 4th and 5th floors to simulate a 4 story building
Direction of air movement unknown

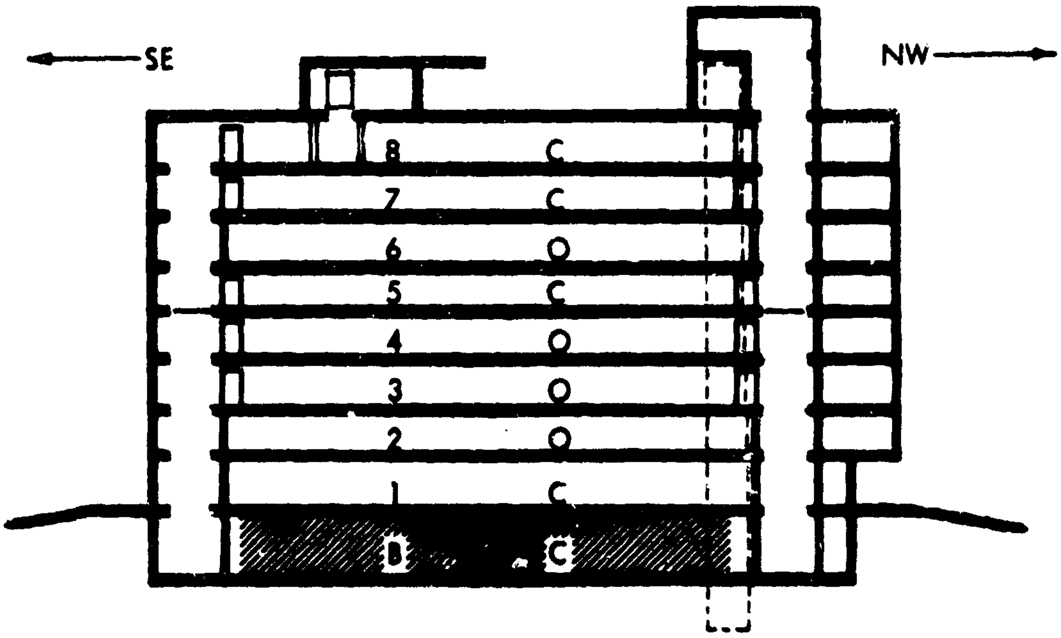
Figure 57

BUILDING B
TEST NO. 2

SHELTER OCCUPANCY
0 persons

LENGTH OF TEST: 5 hours
7/26/65 (0930 hrs) to
7/26/65 (1430 hrs)

RATE OF AIR FLOW
0.85 air changes/hr



C: room doors closed
O: room doors open
▨: simulated shelter

Shelter inlet & outlet, each 18 sq ft

OUTDOOR CONDITIONS

Air dbt:	83 - 72F
Air wbt:	67 - 72F
Relative humidity:	50 - 85%
Wind direction:	N60W
Wind speed:	4 - 15 mph

SHELTER CONDITIONS

Air dbt:	inlet	77.5F
	outlet	77.0F
Air wbt:	inlet	67.0F
	outlet	66.0F
Effective temp:	inlet	73.0F
	outlet	72.0F

SPECIAL CONDITIONS AND COMMENTS

Shelter unoccupied
Stairtowers sealed between 4th and 5th floors
Basement stairtower doors closed but not sealed

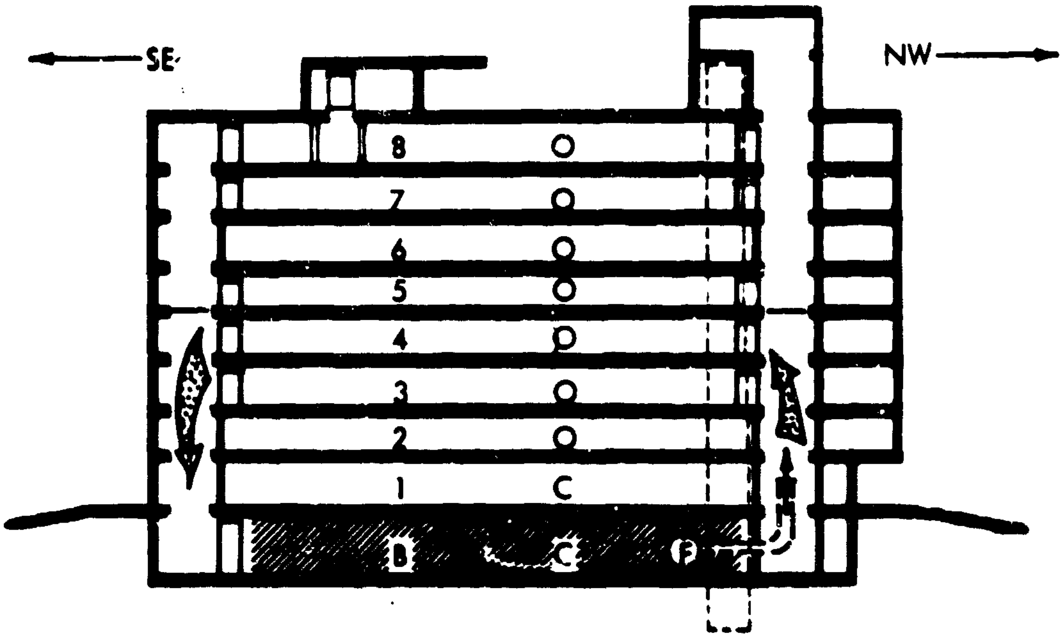
Figure 58

BUILDING B
TEST NO. 3

SHELTER OCCUPANCY
0 persons

LENGTH OF TEST: 1 1/4 hours
7/26/65 (1440 hrs) to
7/26/65 (1600 hrs)

RATE OF AIR FLOW
0.63 air changes/hr



C: room doors closed
O: room doors open
▨: simulated shelter
Ⓕ: pedal fan

Shelter inlet area = 18 sq ft

OUTDOOR CONDITIONS

Air dbt:	82 - 84F
Air wbt:	72 - 74F
Relative humidity:	59 - 62%
Wind direction:	N75W
Wind speed:	11 - 14 mph

SHELTER CONDITIONS

Air dbt:	inlet	78.5F
	outlet	80.0F
Air wbt:	inlet	65.0F
	outlet	67.5F
Effective temp:	inlet	72.5F
	outlet	74.0F

SPECIAL CONDITIONS AND COMMENTS
Shelter unoccupied
Stairtower sealed between 4th and 5th floors to simulate a 4-story building
Pedal fan used in shelter

Figure 59

7.5 PORTABLE PACKAGED VENTILATOR

The protable packaged ventilator, used in Tests No. 3, 14 and 15, was a "Shelter Ventilator Prototype No. 5" manufactured by the American Air Filter, Inc. and supplied by the Office of Civil Defense. A second unit manufactured by the MRD division of General American Transportation did not arrive until the test buildings were to be vacated and therefore was not tested.

The ventilator packaged tested contained a 16 inch fan which could be driven either by a bicycle arrangement with two people pedalling or by a small electric motor which turned the fan at approximately the same speed, 1420 rpm, as people pedalling. Figure 60 is a photograph of this unit operated by the electric motor, but with the bicycle attachment in place.

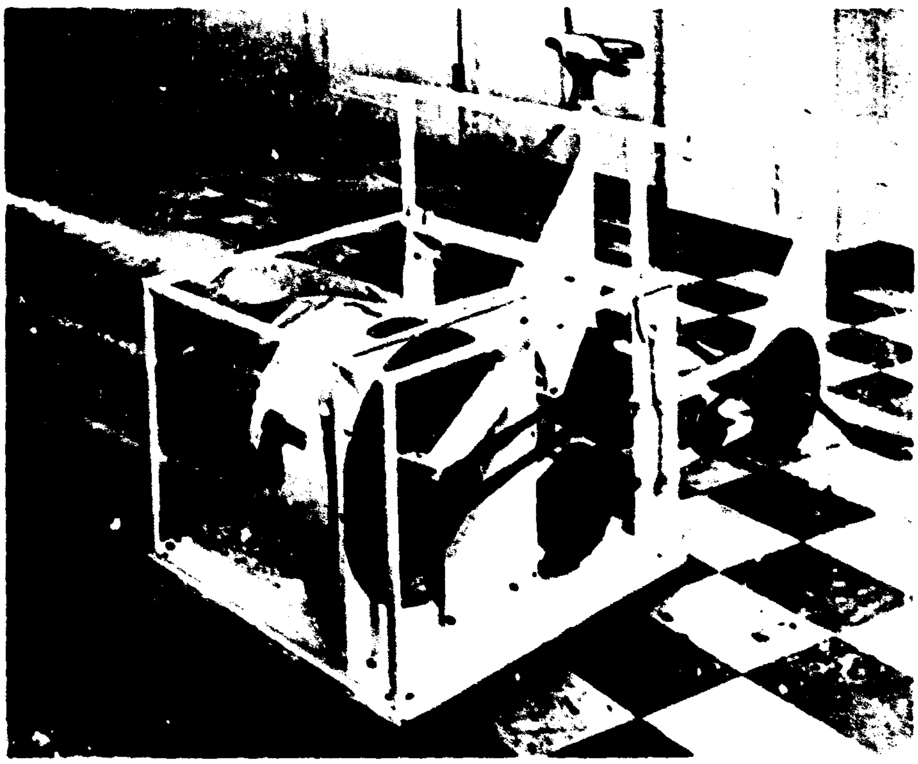


Figure 60. PACKAGED VENTILATION UNIT

Tests were developed to check the differences between natural gravity circulation in a closed building and mechanical circulation in the closed building. The fan was located near the shelter stairtower which served as the outlet stack during gravity circulation. The plastic discharge duct from the fan was run up the stair-tower to the next floor where the air was allowed to discharge inside the building. In order to prevent short circuiting between inlet and outlet of the fan, a plastic sheet was installed in the doorway through which the duct passed, forcing air to be drawn from the shelter space only and not from the stair tower. Thus, the only circulation in the space had to be through the fan. When used in this manner, very little difference could be seen in the tests between the use of the pedal fan and gravity circulation. It was felt that this single unit just about equalled the effects of gravity circulation and when used alone could not increase air flow rates in a space of this size. Another factor which must be recognized is that when used for circulation alone this fan could not be expected to increase the infiltration rate of the building envelope, which was the critical point in a closed space. Had this fan been set up to exhaust air from the building, the results may have been different since there would then have been a change in the infiltration rate of the building.

The fan unit was not difficult to assemble and operate but the flexible 6 mil poly-ethylene plastic duct was not easy to work with. When under pressure the duct would not curve around corners but pinched off thereby restricting air flow. There were no instructions for making bends in the pipe, a task which could be very diffi-cult for the average person to accomplish with the tape and materials supplied with the kit. A second problem was that of holding the end of the duct open, and pre-

venting it from flying around in the stairwell. A duct anchor which holds the end open and secured should be provided in the kit.

Another difficulty was the vibration which caused the fan to walk around the floor. Had people been pedalling the fan, their weight would prevent this, but without the added weight of people the fan had to be wedged into a single location in the corridor. A better set of rubber feet would help control the random walk of the fan.

Research personnel felt that an inlet duct of some rigidity, perhaps provided by a spiral metal liner in a plastic duct, should be included in the kit. If provision were made to attach this to the inlet side of the fan it could be hung near the ceiling to draw off the warmer upper air.

7.6 INDIVIDUAL TEST RESULTS 4 THROUGH 19

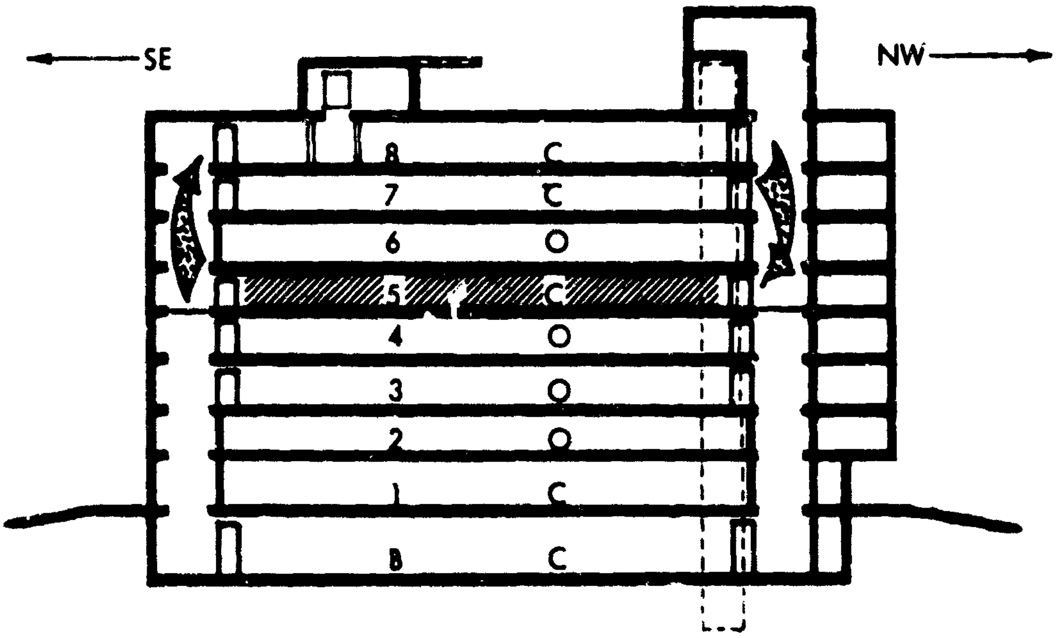
A detailed presentation of tests 4 through 19, one to a page, follows. The last two tests differed from all others because exterior doors were opened, a low one in the inlet stack and a high one in the outlet stack. Since neither external conditions were materially changed nor shelter conditions altered, the substantial increase in ventilation rate is attributed only to those opened exterior doors.

BUILDING B
TEST NO. 4

SHELTER OCCUPANCY
75 persons
33.3 sq ft/person
250 cu ft/person

LENGTH OF TEST: 1 hour
7/27/65 (1740 hrs) to
7/27/65 (1850 hrs)

RATE OF AIR FLOW
1.08 air changes/hr
4.50 cfm person



C: room doors closed
O: room doors open
///: simulated shelter

Shelter inlet
& outlet,
each 38 sq ft

OUTDOOR CONDITIONS

Air dbt:	80 - 79F
Air wbt:	70 - 71F
Relative humidity:	61 - 68%
Wind direction:	N45E - N75E
Wind speed:	8 - 17 mph

SHELTER CONDITIONS

Air dbt:	inlet	85.0F
	outlet	87.0F
Air wbt:	inlet	71.0F
	outlet	73.0F
Effective temp:	inlet	78.0F
	outlet	80.0F

SPECIAL CONDITIONS AND COMMENTS
Stairtowers sealed between 4th and 5th floors

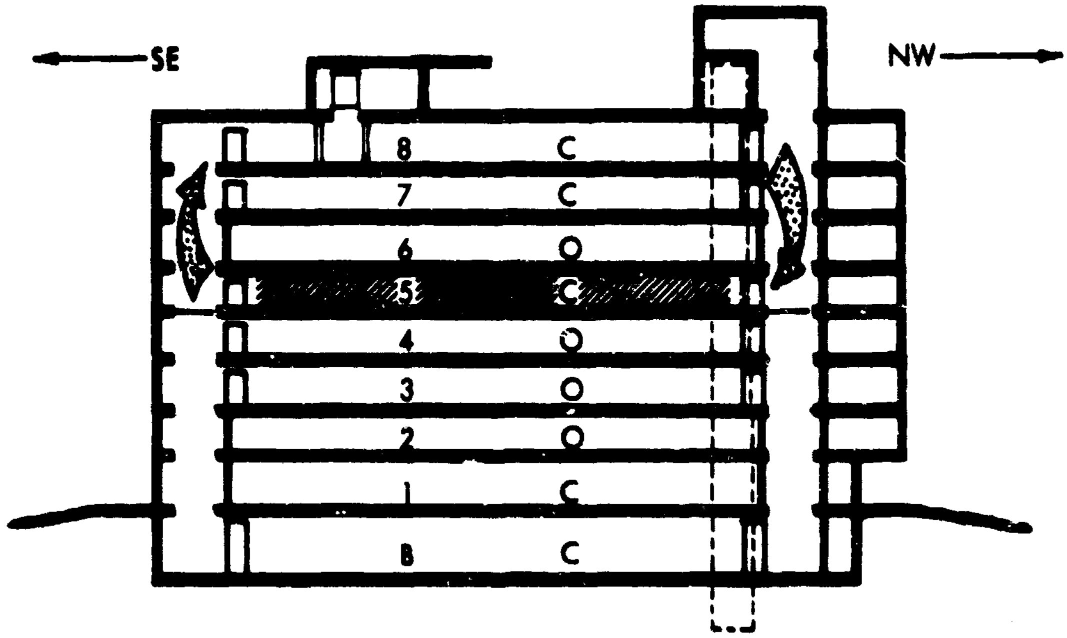
Figure 61

BUILDING B
TEST NO. 5

SHELTER OCCUPANCY
75 persons
33.3 sq ft/person
250 cu ft/person

LENGTH OF TEST: 1 hour
7/27/65 (1900 hrs) to
7/27/65 (2000 hrs)

RATE OF AIR FLOW
1.18 air changes/hr
4.90 cfm person



C: room doors closed
O: room doors open
///: simulated shelter

Shelter inlet & outlet, each 38 sq ft

OUTDOOR CONDITIONS	
Air dbt:	79 - 76F
Air wbt:	71.5 - 70F
Relative humidity:	70 - 75%
Wind direction:	N45E - N75E
Wind speed:	8 - 17 mph

SHELTER CONDITIONS		
Air dbt:	inlet	86.0F
	outlet	87.0F
Air wbt:	inlet	72.0F
	outlet	74.0F
Effective temp:	inlet	78.5F
	outlet	80.0F

SPECIAL CONDITIONS AND COMMENTS

Stairtowers sealed between 4th and 5th floors to simulate a 3-story building above the test space

Figure 62

BUILDING B
TEST NO. 6

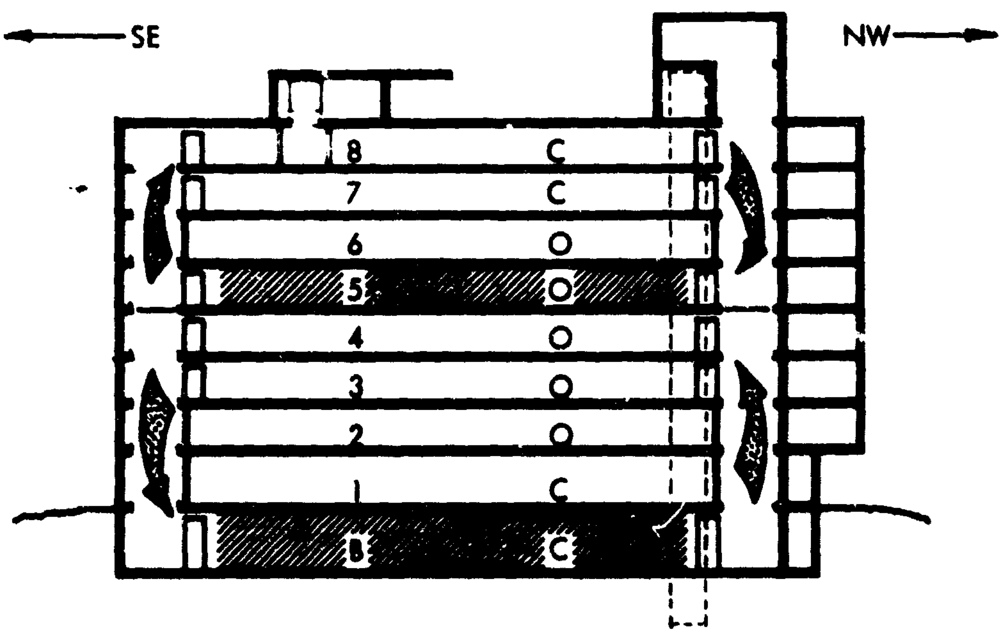
SHELTER OCCUPANCY

	Bsm't	5th fl
persons	75	75
sq ft/person	19	33.3
cu ft/person	190	250

LENGTH OF TEST: 3 hours
7/28/65 (0000 hrs) to
7/28/65 (0300 hrs)

RATE OF AIR FLOW

	Bsm't	5th fl
air changes/hr	1.78	*
cfm person	5.65	*



C: room doors closed
O: room doors open
▩: simulated shelter

Shelter inlet & outlet each in sq ft	Bsm't	5th fl
	18	38

OUTDOOR CONDITIONS

Air dbt:	65 - 60F
Air wbt:	63.5 - 60F
Relative humidity:	88 - 100%
Wind direction:	W - S60W
Wind speed:	4 - 0 mph

SHELTER CONDITIONS

		Bsm't	5th fl
Air dbt:	inlet	80.0F	83.0F
	outlet	83.0F	84.0F
Air wbt:	inlet	69.0F	71.0F
	outlet	71.0F	73.0F
Effective temp:	inlet	75.0F	77.0F
	outlet	77.0F	78.5F

SPECIAL CONDITIONS AND COMMENTS
*Data not taken
Stairtowers sealed between 4th and 5th floor to simulate 4-story and 3-story buildings
75 people simulated in each shelter

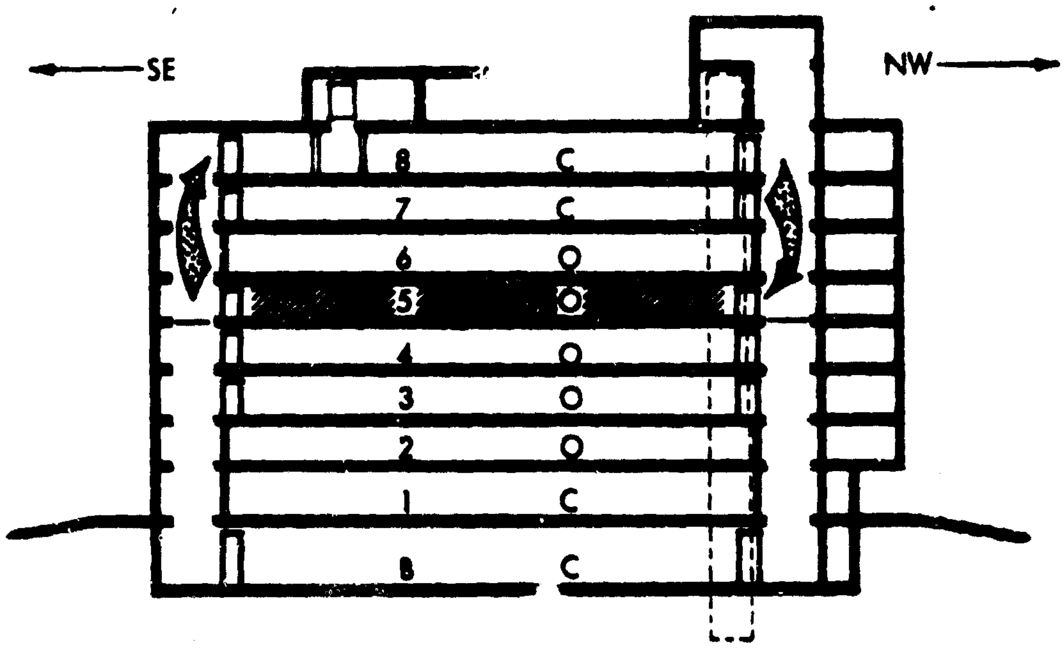
Figure 63

BUILDING B
TEST NO. 7

SHELTER OCCUPANCY
75 persons
33.3 sq ft/person
250 cu ft/person

LENGTH OF TEST: 1 1/2 hours
7/28/65 (2100 hrs) to
7/28/65 (2230 hrs)

RATE OF AIR FLOW
1.55 air changes/hr
6.50 cfm person



C: room doors closed
O: room doors open
///: simulated shelter

Shelter inlet & outlet, each 38 sq ft

OUTDOOR CONDITIONS

Air dbt:	69 - 67F
Air wbt:	62 - 61F
Relative humidity:	68 - 75%
Wind direction:	N30W - N30E
Wind speed:	2 - 6 mph

SHELTER CONDITIONS

Air dbt:	inlet	84.0F
	outlet	85.0F
Air wbt:	inlet	72.0F
	outlet	74.5F
Effective temp:	inlet	78.0F
	outlet	79.5F

SPECIAL CONDITIONS AND COMMENTS
Stairtowers sealed between 4th and 5th floors to simulate a 3-story building above the test space

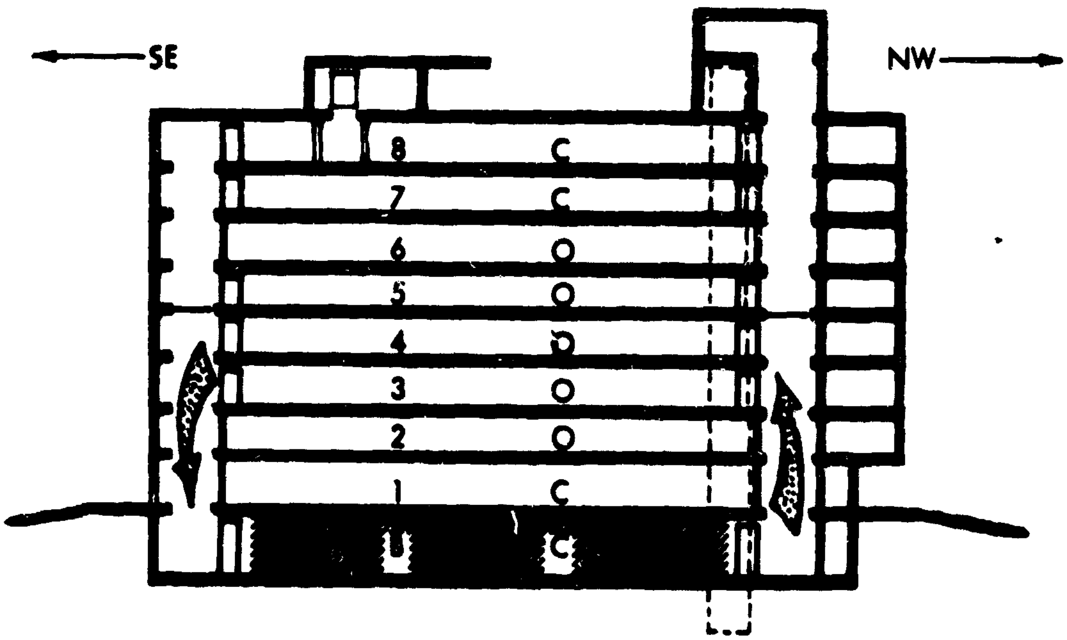
Figure 64

BUILDING B
TEST NO. 8

SHELTER OCCUPANCY
140 persons
10 sq ft/person
100 cu ft/person

LENGTH OF TEST: 1 1/3 hours
7/28/65 (2240 hrs) to
7/28/65 (2400 hrs)

RATE OF AIR FLOW
2.37 air changes/hr
4.00 cfm person



C: room doors closed
O: room doors open
▨: simulated shelter

Shelter inlet & outlet, each 18 sq ft

OUTDOOR CONDITIONS

Air dbt:	68 - 63F
Air wbt:	62 - 60F
Relative humidity:	72 - 85%
Wind direction:	N30W - W
Wind speed:	0 - 2 mph

SHELTER CONDITIONS

Air dbt:	inlet	84.0F
	outlet	85.0F
Air wbt:	inlet	72.0F
	outlet	74.0F
Effective temp:	inlet	78.0F
	outlet	79.0F

SPECIAL CONDITIONS AND COMMENTS
Stairtowers sealed between 4th and 5th floors to simulate a 4-story building

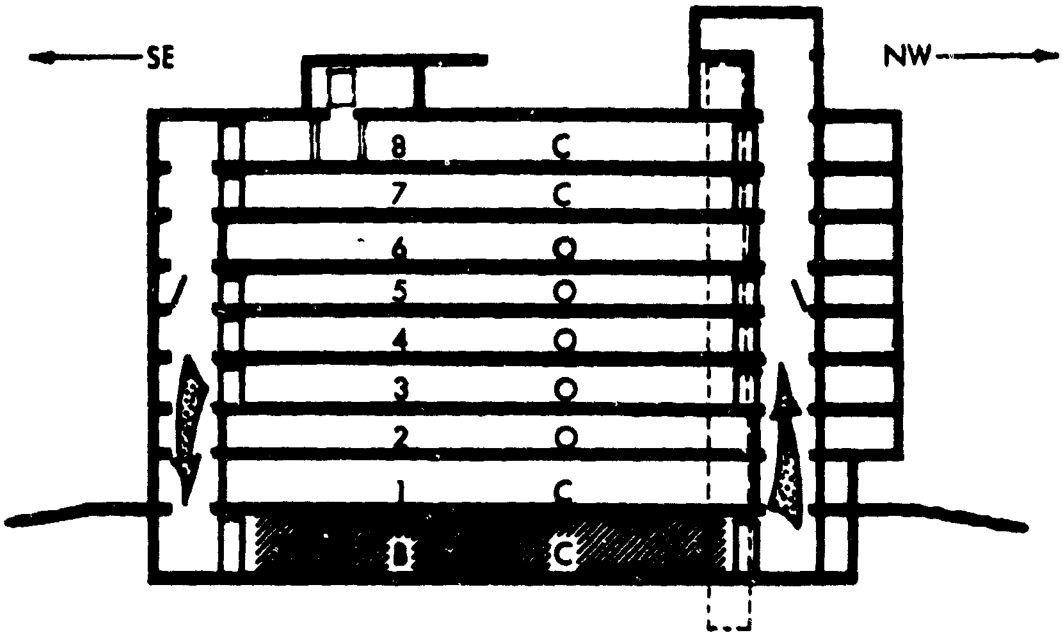
Figure 65

BUILDING B
TEST NO. 9

SHELTER OCCUPANCY
140 persons
10 sq ft/person
100 cu ft/person

LENGTH OF TEST: 1 hour
7/29/65 (0040 hrs) to
7/29/65 (0140 hrs)

RATE OF AIR FLOW
3.57 air changes/hr
6.10 cfm person



C: room doors closed
O: room doors open
▨: simulated shelter

Shelter inlet & outlet, each 18 sq ft

OUTDOOR CONDITIONS

Air dbt:	63 - 61F
Air wbt:	60 - 59F
Relative humidity:	85 - 90%
Wind direction:	W - S60W
Wind speed:	0 - 3.5 mph

SHELTER CONDITIONS

Air dbt:	inlet	80.5F
	outlet	84.0F
Air wbt:	inlet	68.0F
	outlet	69.5F
Effective temp:	inlet	74.5F
	outlet	77.0F

SPECIAL CONDITIONS AND COMMENTS
Stairtowers between 4th and 5th floors opened at 0100 hours

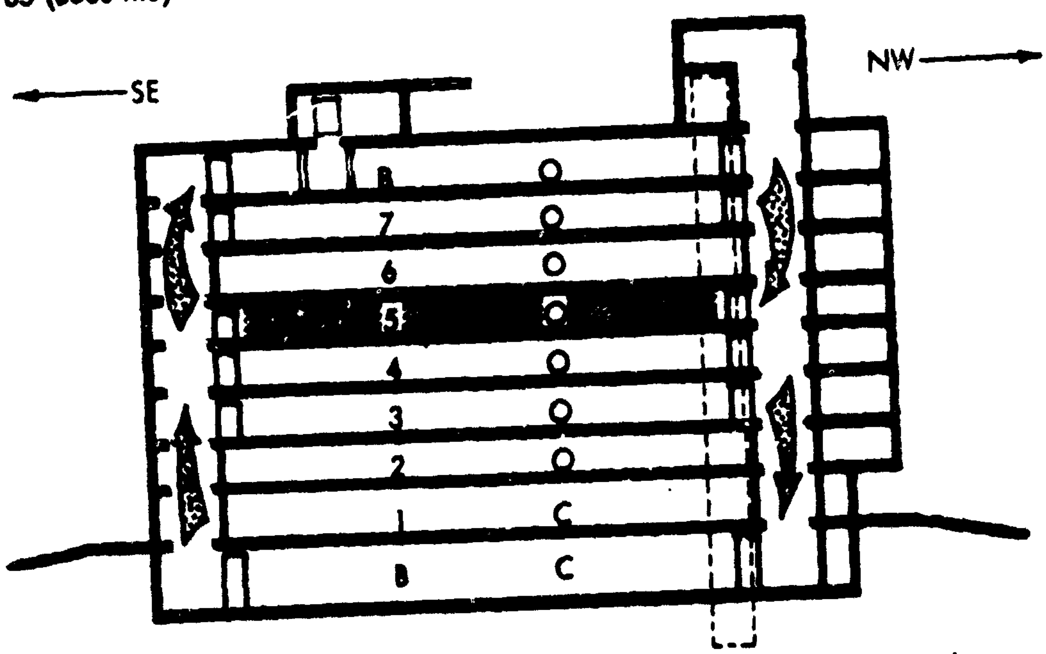
Figure 66

BUILDING B
TEST NO. 10

SHELTER OCCUPANCY
75 persons
33.3 sq ft/person
250 cu ft/person

LENGTH OF TEST: 1 hour
7/29/65 (0200 hrs) to
7/29/65 (0300 hrs)

RATE OF AIR FLOW
0.92 air changes/hr
3.90 cfm person



C: room doors closed
O: room doors open
▒: simulated shelter

Shelter inlet & outlet, each 38 sq ft

OUTDOOR CONDITIONS

Air dbt:	61 - 58F
Air wbt:	59 - 57F
Relative humidity:	90 - 100%
Wind direction:	S60W
Wind speed:	3.5 mph

SHELTER CONDITIONS

Air dbt:	inlet	82.0F
	outlet	83.0F
Air wbt:	inlet	70.0F
	outlet	70.0F
Effective temp:	inlet	76.0F
	outlet	77.0F

SPECIAL CONDITIONS AND COMMENTS
Air movement direction speculative but not proved

Figure 67

BUILDING B
TEST NO. 11

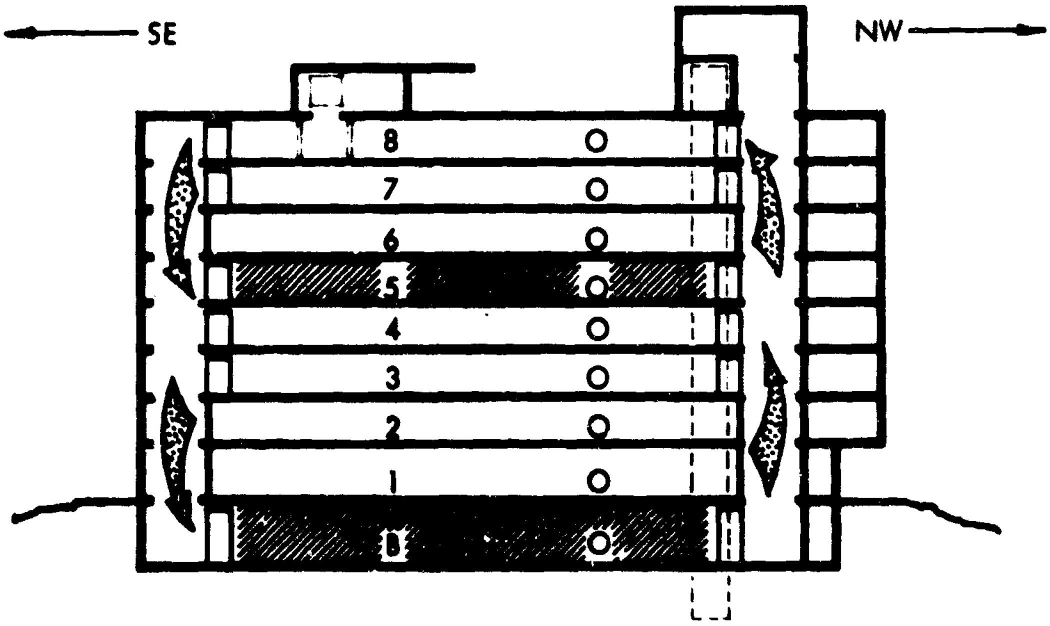
SHELTER OCCUPANCY

	Bsm't	5th fl
persons	140	100
sq ft/person	10	25
cu ft/person	100	188

LENGTH OF TEST: 19 hours
7/29/65 (1600 hrs) to
7/30/65 (1100 hrs)

RATE OF AIR FLOW

air changes/hr	3.72	*
cfm person	6.30	*



C: room doors closed
O: room doors open
▓: simulated shelter

Shelter inlet & outlet, each in sq ft	Bsm't	5th fl
	18	38

OUTDOOR CONDITIONS

Air dbt:	57 - 74F
Air wbt:	57 - 64F
Relative humidity:	55 - 75%
Wind direction:	N30W - S45W
Wind speed:	6 - 9 mph

SHELTER CONDITIONS

		Bsm't	5th fl
Air dbt:	inlet	80.5F	82.5F
	outlet	86.5F	83.0F
Air wbt:	inlet	69.0F	70.5F
	outlet	75.0F	73.0F
Effective temp:	inlet	75.0F	76.5F
		80.0F	78.0F

SPECIAL CONDITIONS AND COMMENTS
*Data not taken
Water feed to 5th floor Simocs shut off 0230 to 0930 hrs because of severe window condensation on upper floors
Sustained rate injection method used

Figure 68

BUILDING B
TEST NO. 12

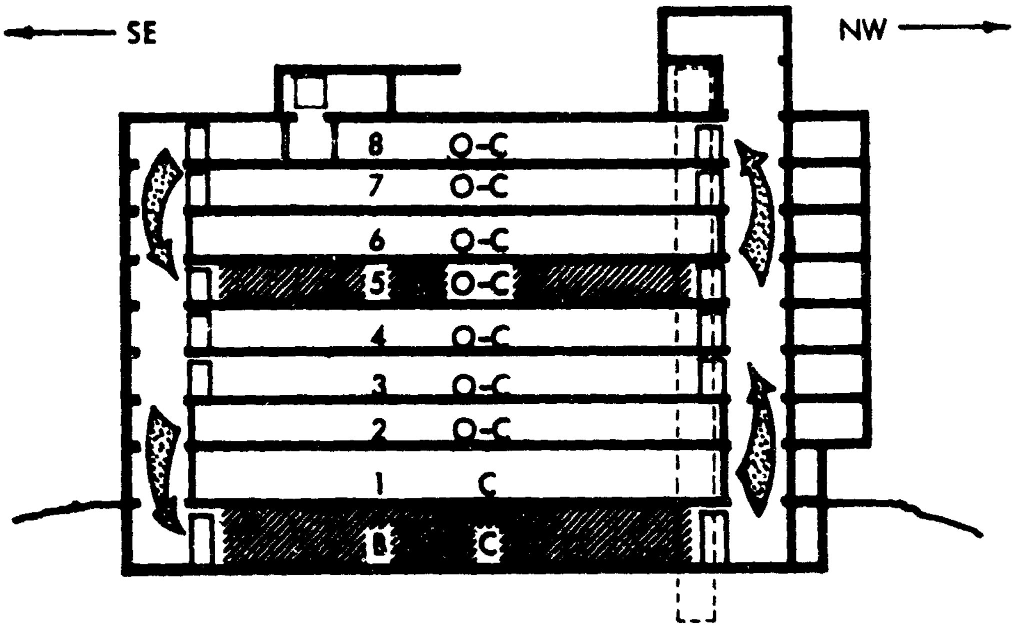
SHELTER OCCUPANCY

	Bsm't	5th fl
persons	140	100
sq ft/person	10	25
cu ft/person	100	188

LENGTH OF TEST: 13 hours
7/30/65 (1100 hrs) to
7/30/65 (2400 hrs)

RATE OF AIR FLOW

air changes/hr	3.22	*
cfm person	3.86	*



C: room doors closed
O: room doors open
▨: simulated shelter

Shelter inlet & outlet, each in sq ft	Bsm't	5th fl
	18	38

OUTDOOR CONDITIONS

Air dbt:	77 - 68F
Air wbt:	63 - 60F
Relative humidity:	37 - 74%
Wind direction:	N45E - N45W
Wind speed:	6 - 9 mph

SHELTER CONDITIONS

		Bsm't	5th fl
Air dbt:	inlet	81.0F	83.5F
	outlet	87.0F	83.5F
Air wbt:	inlet	70.0F	73.0F
	outlet	75.0F	76.0F
Effective temp:	inlet	75.5F	78.0F
	outlet	80.0F	79.5F

SPECIAL CONDITIONS AND COMMENTS
*Data not taken
All room doors closed at 1630 hrs
Sustained rate injection method used

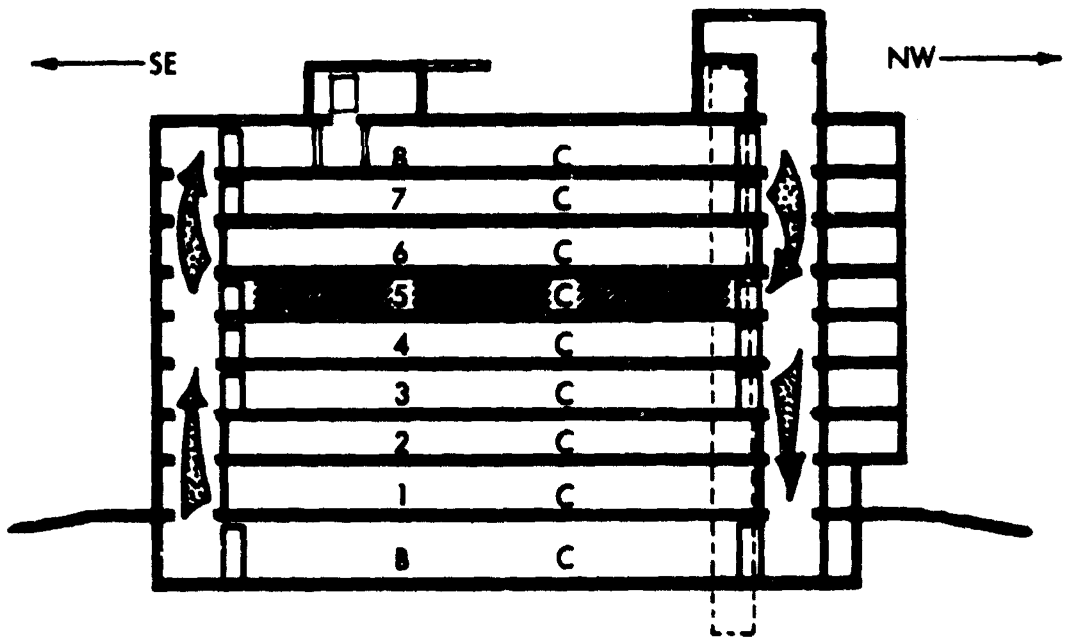
Figure 69

BUILDING B
TEST NO. 13

SHELTER OCCUPANCY
100 persons
25 sq ft/person
188 cu ft/person

LENGTH OF TEST: 4 1/2 hours
8/2/65 (1120 hrs) to
8/2/65 (1400 hrs)

RATE OF AIR FLOW
1.00 air changes/hr
7.25 cfm person



C : room doors closed
O : room doors open
: simulated shelter

Shelter inlet & outlet, each 38 sq ft

OUTDOOR CONDITIONS

Air dbt:	68 - 70F
Air wbt:	64 - 68F
Relative humidity:	81 - 88%
Wind direction:	S60W
Wind speed:	14 - 16 mph

SHELTER CONDITIONS

Air dbt:	inlet	81.5F
	outlet	84.0F
Air wbt:	inlet	71.0F
	outlet	75.0F
Effective temp:	inlet	77.0F
	outlet	77.0F

SPECIAL CONDITIONS AND COMMENTS
Sustained rate injection method used. Rate of flow is based on volume of entire floor. Air movement direction speculative but not proved

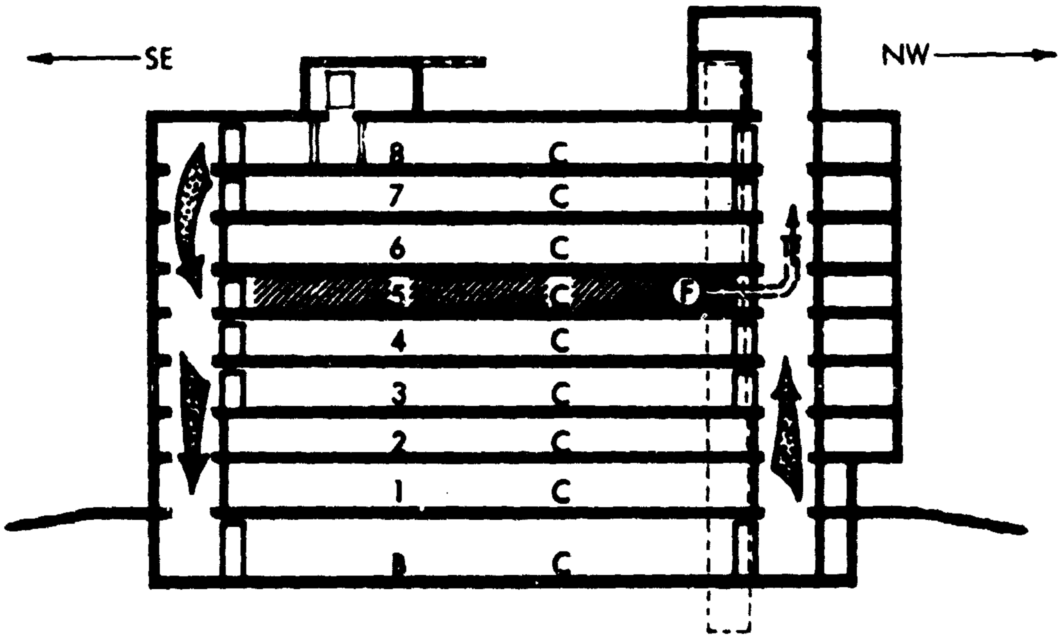
Figure 70

BUILDING B
TEST NO. 14

SHELTER OCCUPANCY
100 persons
25 sq ft/person
188 cu ft/person

LENGTH OF TEST: 4 hours
8/2/65 (1550 hrs) to
8/2/65 (2200 hrs)

RATE OF AIR FLOW *
1.05 - 1.73 air changes/hr
8.40 - 13.80 cfm person



C: room doors closed
O: room doors open
▒: simulated shelter
Ⓕ: pedal fan

Shelter inlet = 38 sq. ft.

OUTDOOR CONDITIONS

Air dbt:	71 - 63F
Air wbt:	67 - 60F
Relative humidity:	81 - 76%
Wind direction:	S60W - N75W
Wind speed:	14 - 16 mph

SHELTER CONDITIONS

Air dbt:	inlet	82.0 - 81.0F
	outlet	82.5 - 88.0F
Air wbt:	inlet	71.0 - 69.0F
	outlet	70.0 - 75.0F
Effective temp:	inlet	76.0 - 75.0F
	outlet	76.0 - 81.0F

SPECIAL CONDITIONS AND COMMENTS
*Double figures indicate before and after pedal fan installation
Pedal fan installed at 1915 hours
Sustained rate injection method used. Rate of air flow is based on volume of entire floor
Air movement direction speculative but not proved

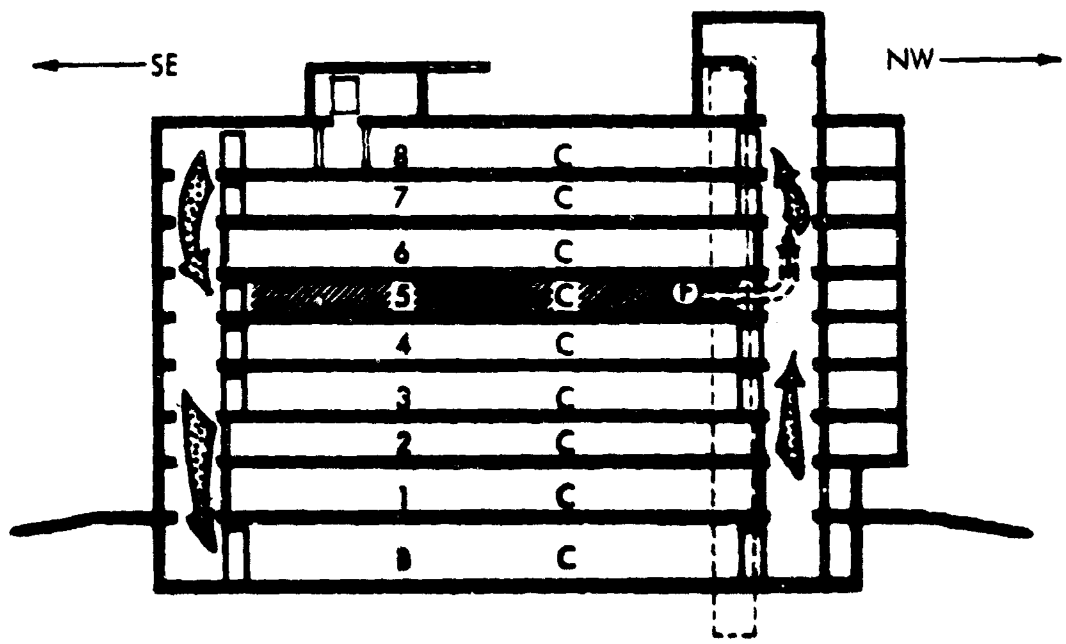
Figure 71

BUILDING B
TEST NO. 15

SHELTER OCCUPANCY
100 persons
25 sq ft/person
188 cu ft/person

LENGTH OF TEST: 1 hour
8/2/65 (2200 hrs) to
8/2/65 (2300 hrs)

RATE OF AIR FLOW
1.58 air changes/hr
4.95 cfm person



C: room doors closed
O: room doors open
▓: simulated shelter
Ⓕ: pedal fan

Shelter inlet area = 38 sq ft

OUTDOOR CONDITIONS	
Air dbt:	63F
Air wbt:	61F
Relative humidity:	92%
Wind direction:	S60W - N75W
Wind speed:	14 - 16 mph

SHELTER CONDITIONS		
Air dbt:	inlet	81.0F
	outlet	88.0F
Air wbt:	inlet	69.0F
	outlet	75.0F
Effective temp:	inlet	75.0F
	outlet	81.0F

SPECIAL CONDITIONS AND COMMENTS
Pedal fan used in shelter
Air movement direction speculative but not proved

Figure 72

BUILDING B
TEST NO. 16

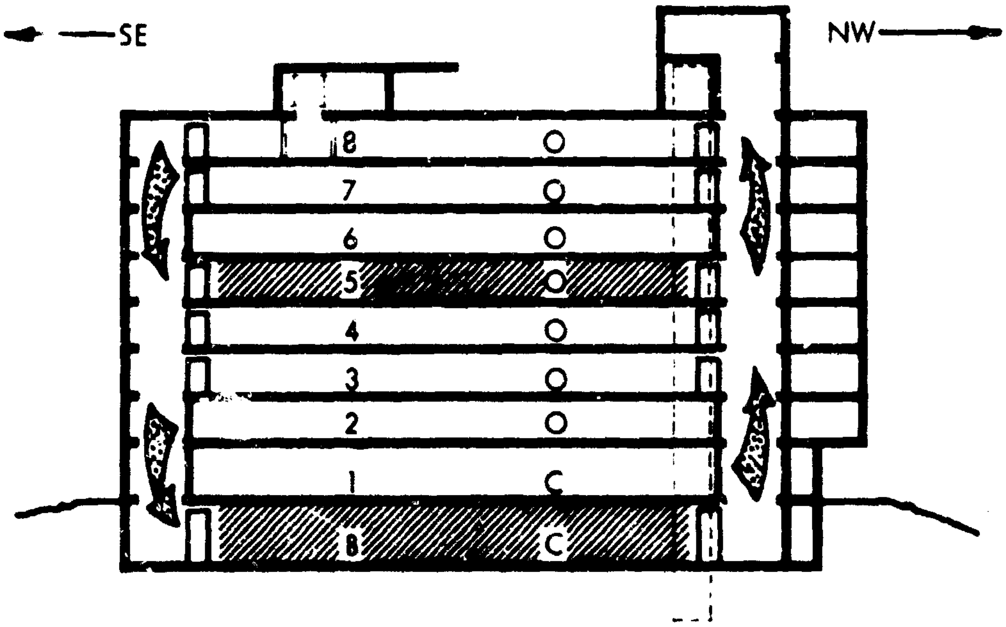
SHELTER OCCUPANCY

	Bsm't	5th fl
persons	140	100
sq ft/person	10	25
cu ft/person	100	188

LENGTH OF TEST: 7 hours
8/4/65 (0900 hrs) to
8/4/65 (1600 hrs)

RATE OF AIR FLOW

air changes/hr	3.50	*
cfm person	2.07	*



C: room doors closed
O: room doors open
▨: simulated shelter

Shelter inlet & outlet, each in sq ft	Bsm't	5th fl
	18	38

OUTDOOR CONDITIONS

Air dbt:	61 - 76F
Air wbt:	57 - 65F
Relative humidity:	80 - 38%
Wind direction:	S15W - N30W
Wind speed:	2 - 9 mph

SHELTER CONDITIONS

		Bsm't	5th fl
Air dbt:	inlet	77.0F	81.0F
	outlet	86.0F	81.5F
Air wbt:	inlet	67.0F	69.0F
	outlet	71.0F	69.5F
Effective temp:	inlet	74.0F	75.5F
	outlet	78.0F	76.0F

SPECIAL CONDITIONS AND COMMENTS

*Data not taken
Sustained rate injection method used
Air movement direction speculative but not proved

Figure 73

BUILDING B
TEST NO. 17

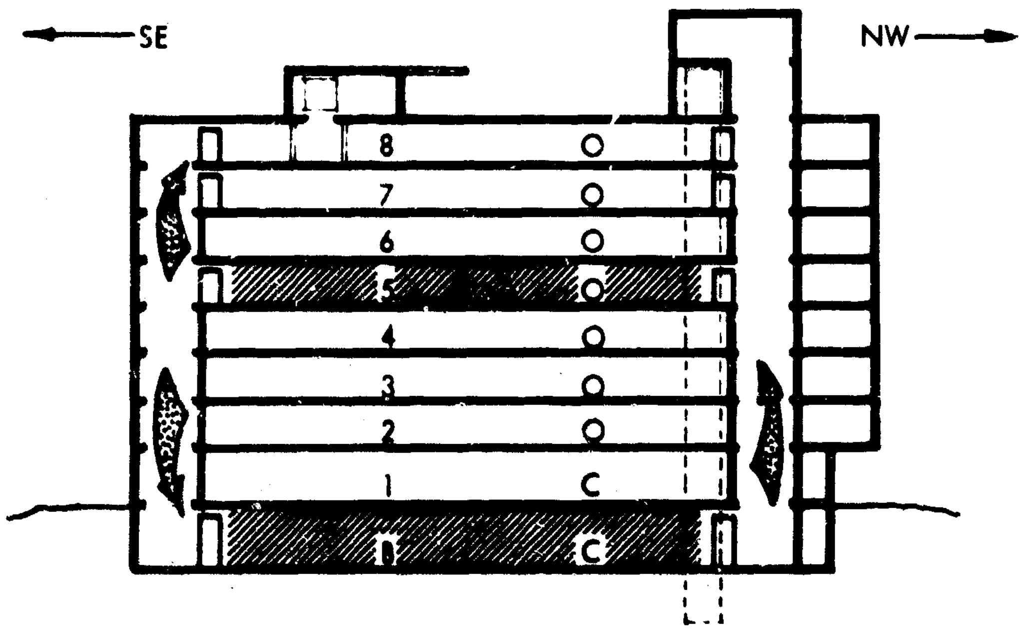
SHELTER OCCUPANCY

	Bsm't	5th fl
persons	140	100
sq ft/person	10	25
cu ft/person	100	188

LENGTH OF TEST: 2 1/2 hours
8/4/65 (1610 hrs) to
8/4/65 (1835 hrs)

RATE OF AIR FLOW

air changes/hr	7.70	*
cfm person	13.20	*



C : room doors closed
O : room doors open
▨ : simulated shelter

Shelter inlet & outlet, each in sq ft	Bsm't	5th fl
	18	38

OUTDOOR CONDITIONS

Air dbt :	74F
Air wbt :	64F
Relative humidity :	58%
Wind direction :	N30E - N30W
Wind speed :	4 - 7 mph

SHELTER CONDITIONS

		Bsm't	5th fl
Air dbt :	inlet	78.0F	82.0F
	outlet	87.0F	83.0F
Air wbt :	inlet	70.0F	71.5F
	outlet	72.0F	74.0F
Effective temp :	inlet	74.0F	77.0F
	outlet	79.0F	78.5F

SPECIAL CONDITIONS AND COMMENTS
*Data not taken
Air movement direction speculative but not proved
Sustained rate injection method used

Figure 74

BUILDING B
TEST NO. 18

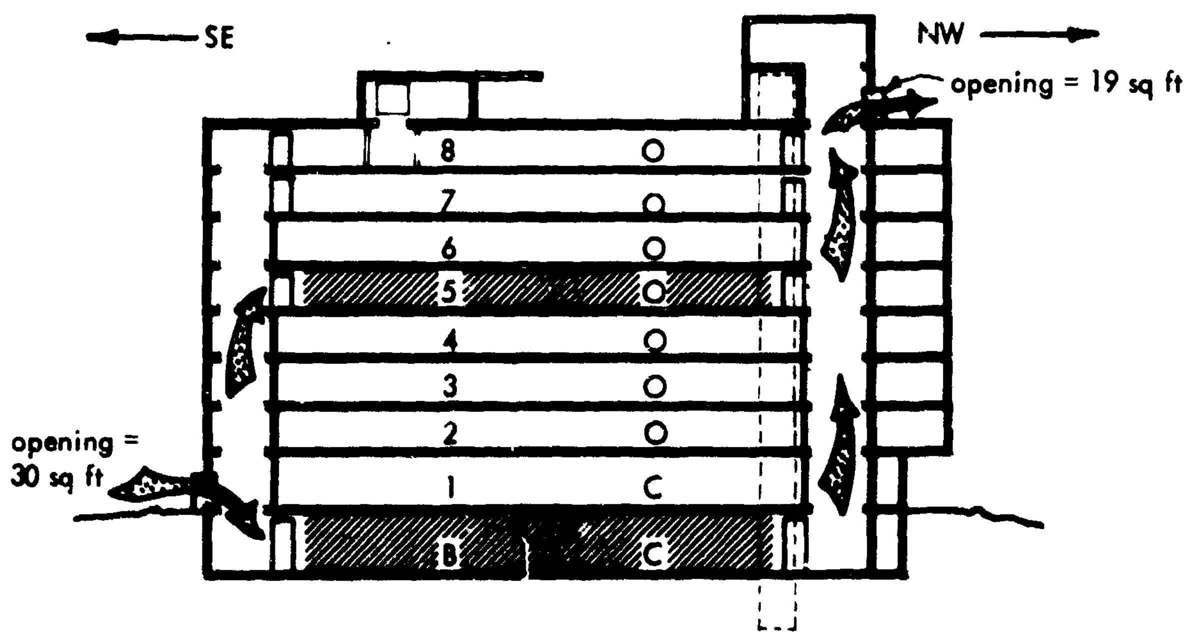
SHELTER OCCUPANCY

	Bsm't	5th fl
persons	140	100
sq ft/person	10	25
cu ft/person	100	188

LENGTH OF TEST: 3 1/2 hours
8/4/65 (1835 hrs) to
8/4/65 (2200 hrs)

RATE OF AIR FLOW

	Bsm't	5th fl
air changes/hr	45.0	*
cfm person	77.0	*



C: room doors closed
O: room doors open
▨: simulated shelter

	Bsm't	5th fl
Shelter inlet & outlet, each in sq ft	18	38

OUTDOOR CONDITIONS

Air dbt:	65F
Air wbt:	65F
Relative humidity:	100%
Wind direction:	S75E - N30E
Wind speed:	0 - 5 mph

SHELTER CONDITIONS

		Bsm't	5th fl
Air dbt:	inlet	67.0F	73.5F
	outlet	80.0F	81.5F
Air wbt:	inlet	63.0F	66.5F
	outlet	68.0F	70.5F
Effective temp:	inlet	66.0F	70.5F
	outlet	75.0F	76.0F

SPECIAL CONDITIONS AND COMMENTS
*Data not taken
Exterior doors to stairtowers opened as shown
Sustained rate injection method used
Stairtower doors at 7th and 8th floor level are open

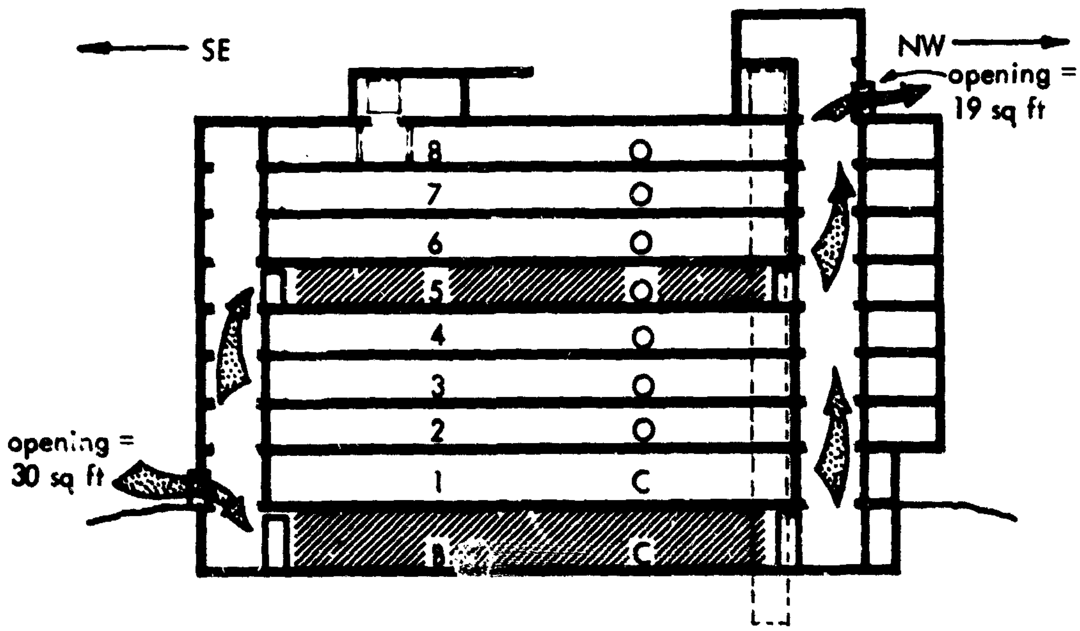
Figure 75

BUILDING B
TEST NO. 19

LENGTH OF TEST: 1 hour
8/4/65 (2200 hrs) to
8/4/65 (2300 hrs)

SHELTER OCCUPANCY

	Bsm't	5th fl
persons	140	100
sq ft/person	10	25
cu ft/person	100	188
RATE OF AIR FLOW		
air changes/hr	10.7	*
cfm person	18.2	*



C: room doors closed
O: room doors open
▨: simulated shelter

Shelter inlet & outlet, each in sq ft	Bsm't	5th fl
	18	38

OUTDOOR CONDITIONS

Air dbt:	64F
Air wbt:	64F
Relative humidity:	100%
Wind direction:	E - S45W
Wind speed:	0 - 1 mph

SHELTER CONDITIONS

		Bsm't	5th fl
Air dbt:	inlet	65.0F	80.5F
	outlet	79.0F	80.5F
Air wbt:	inlet	62.5F	69.0F
	outlet	67.0F	71.5F
Effective temp:	inlet	64.0F	75.0F
	outlet	73.5F	76.0F

SPECIAL CONDITIONS AND COMMENTS

*Data not taken
Exterior doors to stairtowers opened as shown
Stairtower doors at 7th and 8th floor levels are closed
Sustained rate injection method used
Possible reason for the fourfold decrease in basement shelter ventilation rate, compared with Test No. 18, is the decrease in wind velocity

Figure 76

SECTION 8.0

SUMMARY AND CONCLUSIONS

SECTION 8.0 SUMMARY AND CONCLUSIONS

8.1 GENERAL SUMMARY

Summary and conclusions of this project have been separated into four parts for the convenience of the reader. The first part deals with methods of measurement of air change rate, the second part with natural ventilation in unoccupied buildings, the third part with natural ventilation for occupied shelter spaces and the fourth part with suggestions for continued research. Because of the complexity of factors involved, conclusions are based on a minimum number of tests and observations. Figures, where given, are conservatively stated to allow for increased deviation which could rightfully be expected if the number of tests were expanded. It is necessary to emphasize once again that weather conditions were mild for the location and time of year, that shelter spaces were not loaded to the usual density of 1 person per 10 square feet, and that indoor effective temperature was kept below 85F in order to avoid damage due to excessive condensation. Furthermore, all conclusions apply only to the particular type of building tested and only to this specific climatic condition.

8.2 MEASUREMENT OF AIR CHANGE RATE

(1) The electronegative gas detector, using SF_6 as a tracer gas, is a satisfactory and reliable method for measuring air change rates in multi-story buildings (Section 2.0).

(2) There was good correlation between sustained rate of injection and decay rate (Section 2.2).

(3) Tracer gas should be diluted with air prior to distribution in order to increase the quantity and thereby attain better mixing within the test space (Section 2.4).

(4) Gas distribution to the test space and return of air samples from the test space was accomplished conveniently and economically by the use of 1/2" diameter plastic pipe (Section 2.3).

(5) Uniform tracer gas concentrations throughout the building at the beginning of an observation is an ideal condition never realized. Differences in infiltration rates and differences in tracer gas injection rates make uniform concentration difficult to attain and of short duration.

8.3 NATURAL VENTILATION IN AN UNOCCUPIED BUILDING

(1) Both buildings used in this project, of identical size and plan, of same construction and age, were found to be equally tight (Figure 35). On the basis of this limited experience, it should be possible to predict infiltration rates based on data that might be accumulated concerning construction features. Additional research in this area is needed.

(2) When outdoor air temperature was higher than indoor air temperature, decay rates of tracer gas were nearly equal for all floors (Section 6.4).

(3) When outdoor air temperature was lower than indoor air temperature, decay rates of tracer gas were higher for lower floors (Section 6.4). This was due to the influence of air entering the building at lower levels because of upward convection within the building.

(4) In the absence of heat sources, such as shelter occupants, there was relatively little upward convection within a building under the conditions encountered in this project (Section 6.2).

(5) Changing outdoor air temperatures appeared to have very little effect on the infiltration rate (Figure 46).

(6) Winds up to 15 mph had no perceptible effects on the infiltration rate in closed buildings of this type (Figure 46).

(7) On floors with masonry walls and relatively small glass areas (under 25%) there was very little correlation between outdoor air temperature and indoor air temperature (Figure 44).

(8) When the building skin consists of large areas of glass, the indoor temperature responds quickly and unmistakeably to changes in outdoor temperature (Figure 44)

(9) Basement temperatures responded very slowly, if at all, to changing outdoor temperature (Figure 44).

(10) In relatively mild weather, when outdoor air temperature was lower than indoor air temperature, fresh air change rates were higher in lower floors and diminished progressively toward the top of the building (Figures 47 and 48).

(11) In basement spaces generally, when outdoor air temperature was lower than indoor air temperature, fresh air change rates varied between 1 and 1 1/2 per hour (Figure 47).

(12) From second to fourth floors, when outdoor air temperature was lower than indoor air temperature, fresh air infiltration rates varied between 1/2 and 1 per hour (Figure 50).

(13) Above the fourth floor, when outdoor air temperature was lower than indoor air temperature, fresh air infiltration rates varied between 1/4 and 1/2 per hour (Figure 50).

(14) When the outdoor air temperature was higher than indoor air temperature, infiltration rates of fresh air were even lower, less than 1/4 per hour (Figure 47).

8.4 NATURAL VENTILATION FOR OCCUPIED SHELTER SPACES

(1) In basement shelter space of a 4 story building in warm weather, with occupancy based on 1 person per 10 square feet, highest E.T. was 79 F, fresh air infiltration was 4 cfm per person (Test 88).

(2) In basement shelter space of an 8 story building in cool weather, with occupancy based on 1 person per 10 square feet, highest E.T. was 77 F, fresh air infiltration was 6 cfm per person (Test 9B).

(3) In fifth floor shelter space of an 8 story building in cool weather, with occupancy based on 1 person per 33 square feet, highest E.T. was 79-1/2 F, fresh air infiltration varied between 4 and 6-1/2 cfm per person. Shelter could have accommodated more occupants (Tests 7B and 10B).

(4) In simultaneous loading of an 8 story building in cool weather, basement occupancy based on 1 person per 10 square feet and fifth floor occupancy based on 1 person per 25 square feet, highest E.T. in basement was 78 F with fresh air infiltration of 3 1/2 cfm per person (fifth floor data not taken). Shelters could have accommodated more occupants (Tests 12B and 16B).

(5) In a fifth floor shelter space during cool weather, with occupancy based on 1 person per 25 square feet, use of a single portable ventilation fan appeared to increase the circulation rate substantially. Highest E.T. was 81 F indicating that shelter could have accommodated more occupants (Test 14B).

(6) The highest air change rate developed during moderate weather, with basement shelter occupancy based on 1 person per 10 square feet and fifth floor shelter occupancy based on 1 person per 25 square feet was 13 cfm per person in the basement (fifth floor data not taken). Highest E.T. was 79 F indicating that shelter could have accommodated more occupants (Test 17B).

(7) Opening an exterior door at the bottom of inlet stair tower and at the top of outlet stair tower increased fresh air ventilation rate considerably. With basement shelter occupancy based on 1 person per 10 square feet and fifth floor shelter occupancy based on 1 person per 25 square feet, two separate tests produced basement rates of 77 cfm per person and 18 cfm per person with highest E.T. of 75 F and 73.5 F respectively.

8.5 SUGGESTIONS FOR CONTINUED RESEARCH IN NATURAL VENTILATION FOR SHELTER SPACES

Additional research should be conducted in the field of natural ventilation utilizing the tracer gas technique developed in this project. Specifically, additional research should be based on the following procedures:

(1) Establish maximum occupancy levels which maintain a habitable thermal environment under natural ventilation conditions and under closed conditions when concurrent loading of all potential shelter spaces of a multi-story building is maintained. The shelter spaces used for these tests should be those designated under the National Shelter Survey as public shelter space.

(2) Evaluate the effects of loading all shelter spaces of a multi-story building to current standards of one person per 10 square feet, and develop experimental procedures (open windows, door, etc.) using natural ventilation to maintain a habitable thermal environment.

(3) If it is not possible to maintain a habitable thermal environment in (2) above, determine maximum loading in terms of square feet per person which can be tolerated using natural ventilation.

(4) Conduct studies to determine the feasibility and limitations of natural ventilation in above ground fallout shelters.

(5) Compare the efficacy of natural ventilation in basement and above ground shelter spaces.

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APPENDIX

APPENDIX

EXAMPLE OF AIR CHANGE DETERMINATION

Data for these tests were recorded on a Heath servo-chart recorder which was connected to EGAD, and shown on the right of Figure 14. Concentration levels from this chart could not be directly plotted against time on semi-log paper because the EGAD did not have a linear scale, explained on page 33 of this report. It was therefore necessary to transfer data through the EGAD calibration curve shown in Figure 18. Points were then plotted for each floor, concentration vs time, on semi-log graph paper. Figure 77 is a plot of results for Test 15A. A straight line was established through the plotted points with ventilation rate indicated by steepness of line slope. Details of the method are given on page 19.

A family of curves, shown in Figure 78 for Test 15A, was then plotted to show the decreasing concentration of tracer gas on each floor with the passage of time. An inspection of such a family of curves indicates generally that the change in concentration with time takes place more rapidly on the lower floors, and decreases on a floor by floor basis toward the top of the building. This can be explained by the fact that fresh air flows into the building at the lower levels and creates a rapid decrease in concentration, while at the upper levels SF_6 laden air moving up from below products a prolonged concentration of the tracer gas.

Test 15A has been presented as a typical example of the procedure followed in the project. Other tests are similar.

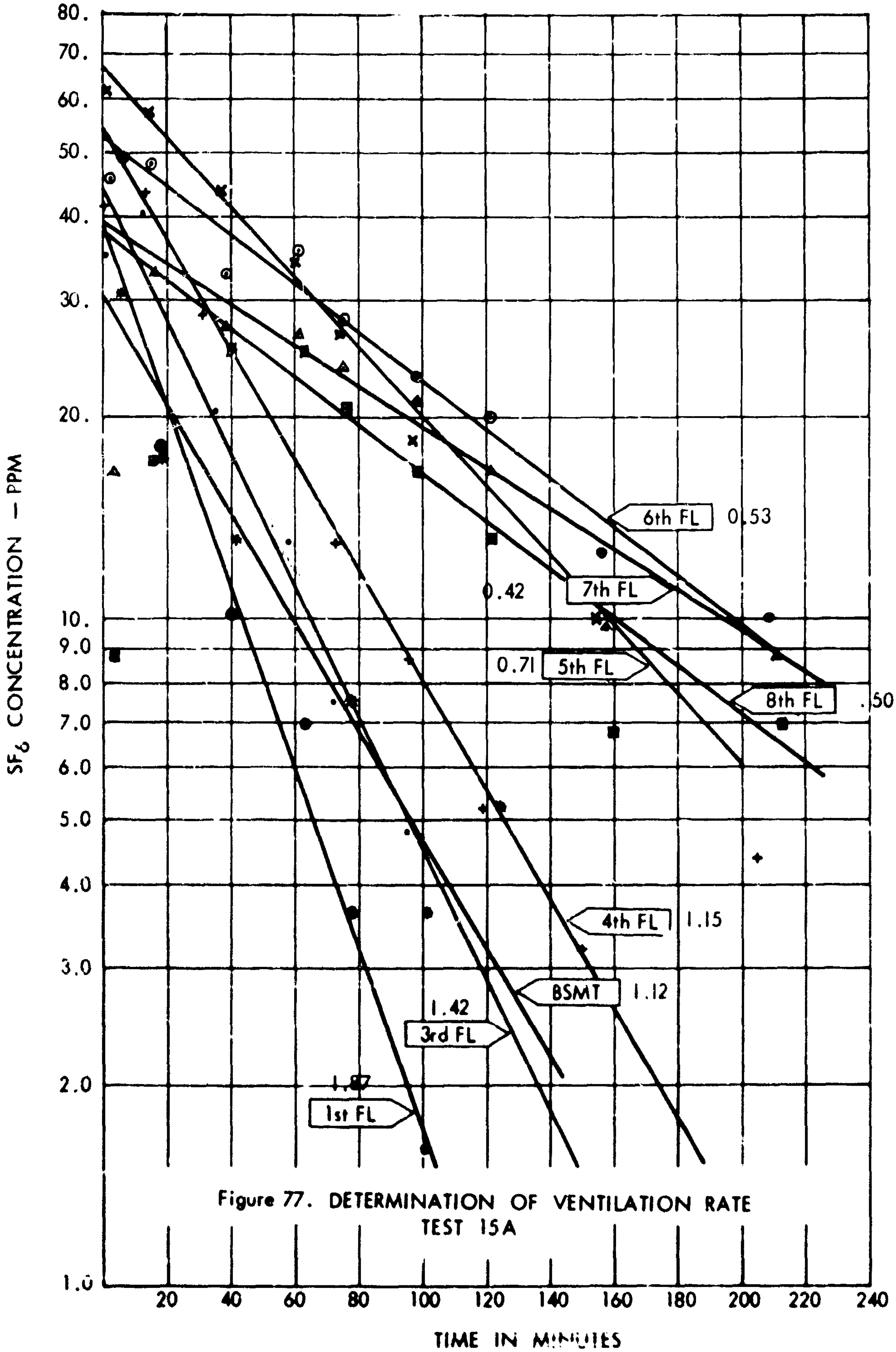

Figure 77. DETERMINATION OF VENTILATION RATE
TEST 15A

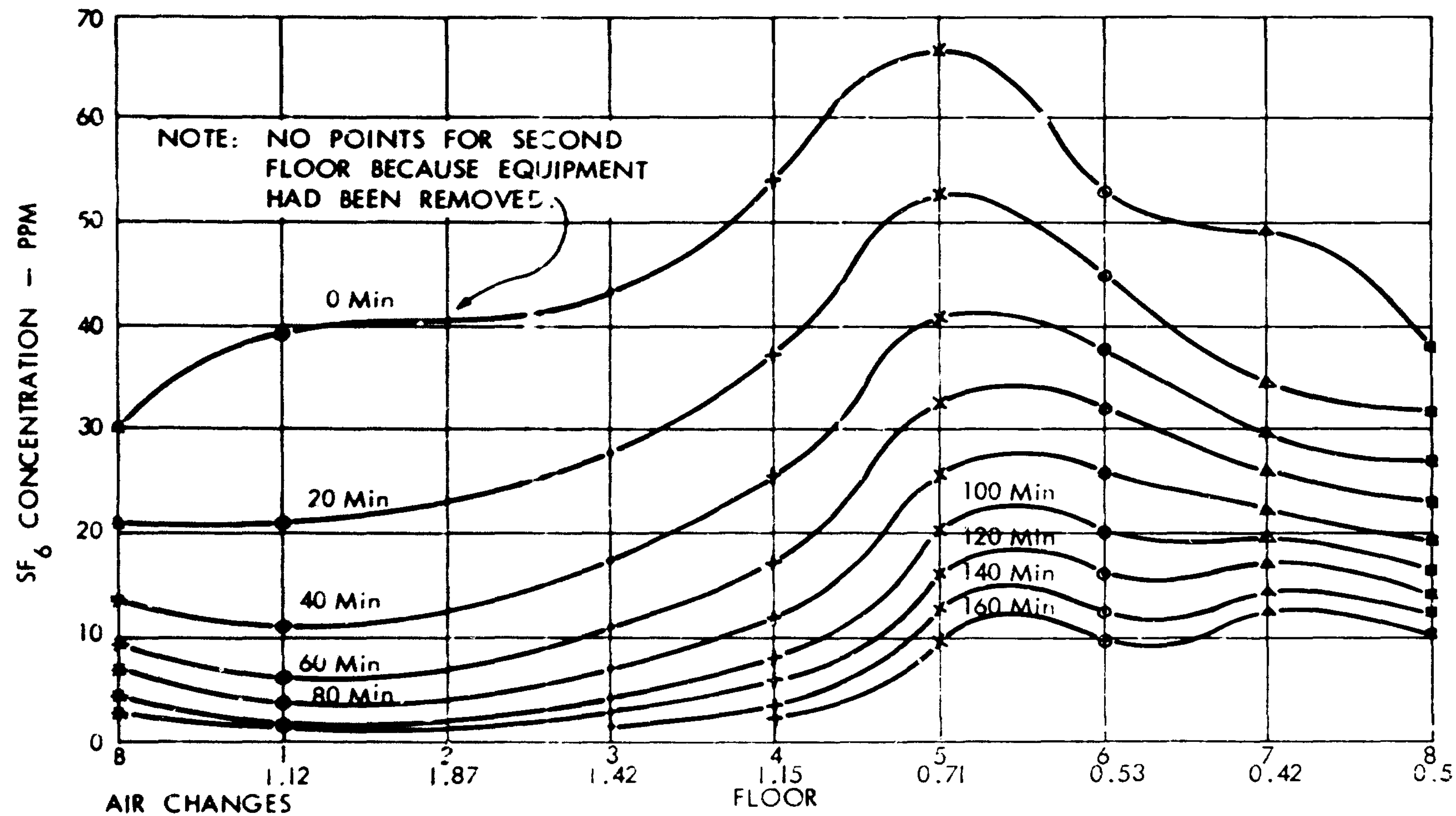

Figure 78. GAS CONCENTRATION vs TIME - TEST 15A